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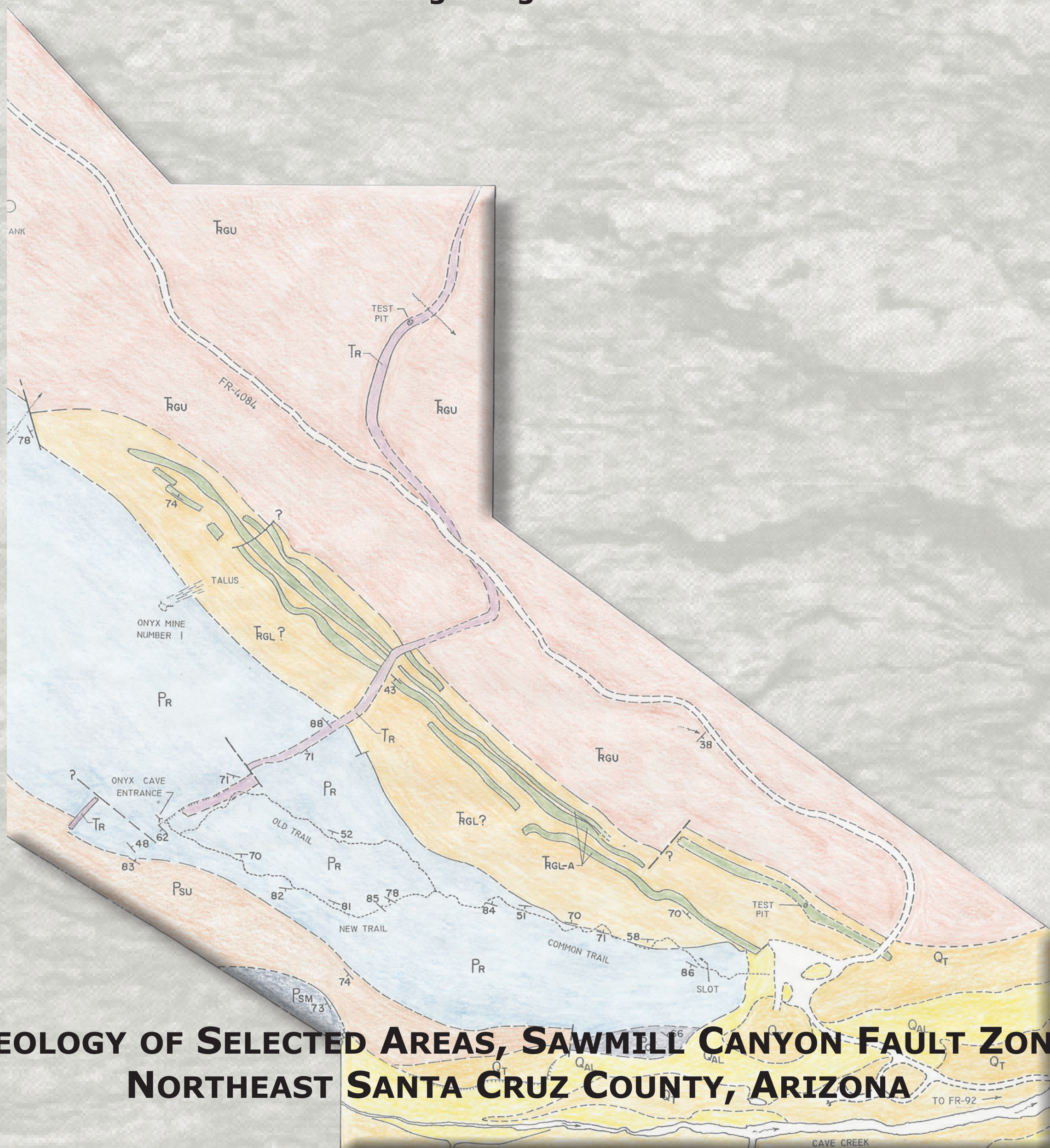

Geology of Selected Areas, Sawmill Canyon Fault Zone Northeast Santa Cruz County, Arizona

Langford G. Brod, Jr.

2010

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by Langford G. Brod Jr.

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Table Of Contents

List Of Illustrations

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General Introduction

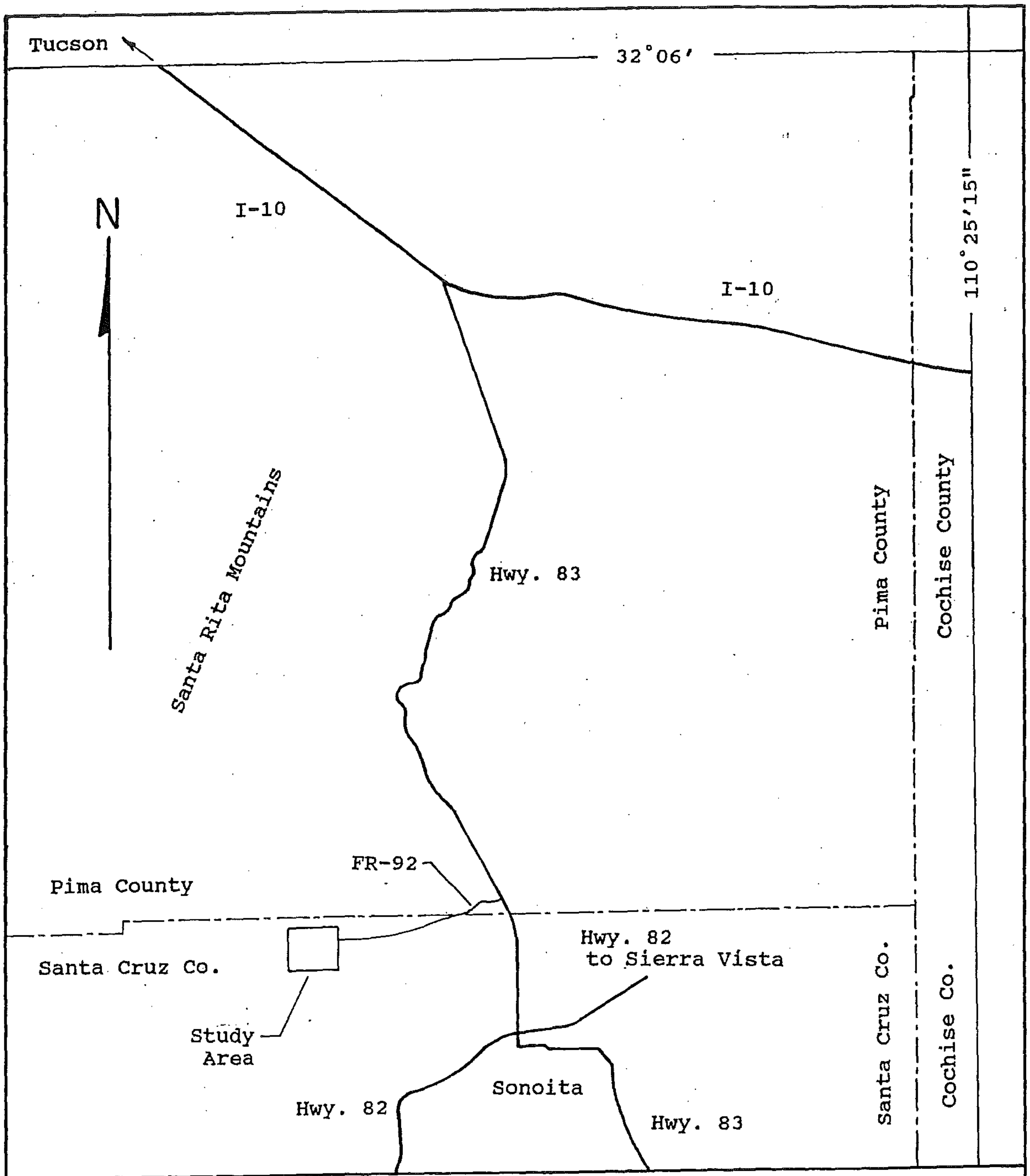
In 1991, with the encouragement of the U.S. Forest Service, I and a number of members of Escabrosa Grotto (a chapter of the National Speleological Society) began mapping a large cave, Cave Of The Bells in northeastern Santa Cruz County, Arizona. While entering the cave on 20 February 1994, I noted faulting in the entrance rock. On the same day, I decided to begin a survey of the surface geology. The survey was aided by a geologic study published by the United States Geological Survey: The Structural Geology of the Santa Rita Mountains, Southeast of Tucson, Arizona (1972), by Harald Drewes.

In subsequent years I surveyed a number of areas lying along the same trend, a section of Sawmill Creek. The next area was on the north side of Forest Road 92, at the extreme eastern limit of Paleozoic and Mesozoic rocks, and adjacent to Apache Spring Ranch. I termed this area Apache Ridge, after the ranch and spring.

The next area to be surveyed was a somewhat larger area lying between the confluence of Sawmill Creek and the next stream crossing where Forest Road 4085 crosses Sawmill Creek. I termed the map area Lower Sawmill Creek. The next area mapped was on the north-northwest side of FR-4085, Which I named Hilton Ridge after the small cave near the eastern end of the area.

The next area surveyed was the Onyx Cave area, about 0.8 mile (1.2 km) south of Cave Of The Bells, which I named Onyx Hill. Thus, five major map areas were prepared. along with several auxiliary maps showing related areas of interest related to the primary maps. All major areas were surveyed at a scale of 50 feet per in inch and later reduced to 100 and 200 feet per inch; several auxiliary areas were surveyed at scales of 10 and 20 feet per inch to show details. After finishing surveying of Onyx Hill additional features were surveyed in several of the other map areas to clarify certain areas and fill in blanks. The general location is shown in Figure 1; the five major areas are shown in Figure 2.

The five major areas are discussed separately, for the most part, except in those cases where features in one map area may bear upon features in another map area. All areas were surveyed on foot to obtain the best accuracy. In a few cases, the position of certain features or the identification of formations was obscure; in those cases I used my best judgment. To facilitate accuracy, multiple station lines and triangulation was used in many areas. In many areas, geographic and man-made features are included to permit geologic features to be found, if required. On the Apache Ridge map area, three Forest Service survey markers were found, two along the road (FR-92) and one not far from the Arizona Trail; details on these markers are included in an appendix.



LOCATION OF STUDY AREA IN SOUTHEASTERN ARIZONA

FIGURE 1

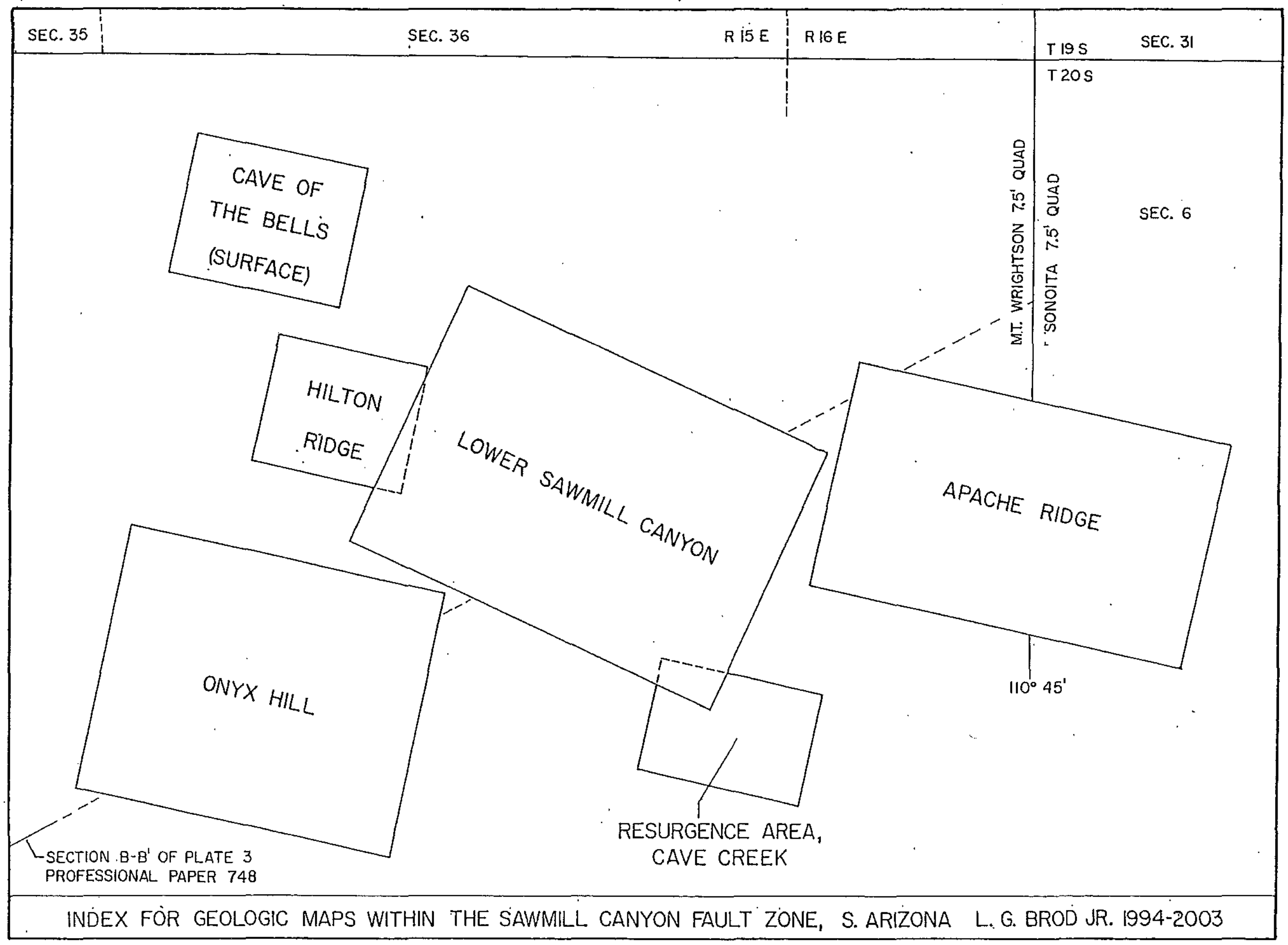

SEC. 35
SEC. 36
R 15 E
R 16 E
T 19 S
SEC. 31
T 20 S
M.T. WRIGHTSON 7.5' QUAD
SONOITA 7.5' QUAD
SEC. 6
CAVE OF THE BELLS (SURFACE)
HILTON RIDGE
LOWER SAWMILL CANYON
APACHE RIDGE
ONYX HILL
110° 45'
RESURGENCE AREA, CAVE CREEK
SECTION B-B' OF PLATE 3 PROFESSIONAL PAPER 748
INDEX FOR GEOLOGIC MAPS WITHIN THE SAWMILL CANYON FAULT ZONE, S. ARIZONA L. G. BROD JR. 1994-2003

FIGURE 2

The Geology Of Apache Ridge - Introduction

Apache Ridge is a name that was chosen by the author to describe a topographic feature, previously unnamed, lying north of Apache Spring, The authenticity of the name applied to the spring is unknown, and the possible presence of the Apache people in this area is not known to the author. The location is shown in Figure 2.

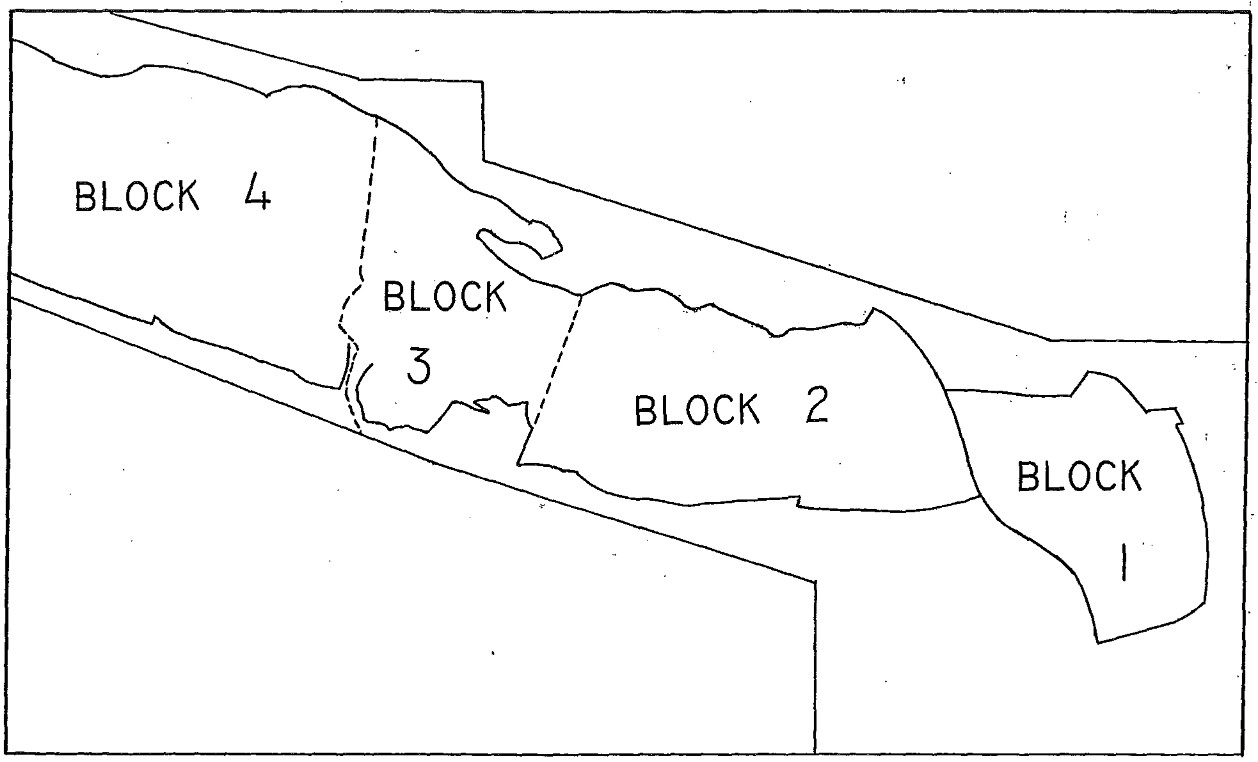
The ridge extends eastward about one mile along the north side of Gardner Creek valley before terminating; to the west it merges into a plateau. An unpaved, gravel road established by the Forest Service, FR-92, runs west along the base of the ridge, along the northern boundary of Apache Spring Ranch. The core of the ridge is composed of Paleozoic limestones bounded by Mesozoic siltstones containing a few thin limestone beds. The limestone core of the ridge curves to the southeast and essentially terminates at the gravel road. A survey of the surface geology was begun in 1998 and essentially ended in 1999, except for small bits surveyed in 2001 and 2004. The primary objective of the survey was an attempt to determine the source of water emerging at the spring. No definite source was found, but it was thought the ground water originated on the plateau area northwest of the spring and moved southeastward in the carbonates exposed on the ridge.

The valley south of the forest road is almost flat from the road to Gardner Creek, a normally dry stream at the base of a steep slope which rises to an almost flat plateau. The crest of the plateau stands about 100 meters above the creek and is the remnant of coalesced alluvial fans resulting from deposition in Pliocene time. A thin remnant of the very coarse gravel deposited at an earlier time remains at the crest of Apache Ridge. Subsequent Pleistocene to Recent erosion removed most of the gravel from the ridge and cut into the siltstones at the ranch.

The erosion also exposed several bodies of volcanic rock, which are visible in a few places along Cave Creek and Gardner Creek, on the south side of the ridge. A rhyolite dike is exposed on the Sawmill Canyon map, immediately west of Apache Ridge. Other volcanic rock is exposed in a low ridge between Sawmill Canyon and the Onyx Cave area to the south. An igneous batholith is exposed south of Cave Creek and the Onyx Cave area.

A geological report, Professional Paper 748, was published by the United States Geological Survey in 1972. The author, Harald Drewes discussed the structure and stratigraphy of three areas in the Sonoita area, with the emphasis primarily on the structure of the three areas, at a scale of 1000 feet per inch. Plate 3, which was devoted to the Sawmill Canyon Fault zone, proved to be of great value to this study, although it covered only part of Apache Ridge.

To facilitate description of Apache Ridge, it has been divided into four blocks, from block 1 on the eastern end to block 4 on the western end, as shown on Figure 3. The boundaries of the blocks are based on faults or other features, a fence and the Arizona Trail.



DIVISION OF APACHE RIDGE GEOLOGIC AREA
(TO FACILITATE DESCRIPTION OF DETAILS)

FIGURE 3

Stratigraphy of Apache Ridge

Colina Limestone

Prior to surveying Apache Ridge, it was necessary to find a suitable place to start. For this purpose, a traverse north along the Arizona Trail and an ascent was made to the top of the ridge, running in a generally east-west direction. The initial survey was along the trail from the southern edge of the limestone to the northern edge of the limestone, which was almost a width of 200 meters, and which was close to being a central axis.

Using this central traverse, the survey was extended E-SE and W-NW, eventually covering the area in question. Using fossils and lithologic features, it was possible to determine the stratigraphy of the various outcrops.

Shortly after beginning the survey, the eastern margin of the outcrops, was found, which occurred in a small ravine beginning on the north side of the road near an old ranch house and initially extending northward. The edge of the outcrops curved around to a westward direction and the slope diminished toward the crest. In this area were a number of exposures of dark gray limestone, and in some were large gastropod fossils, index fossils for the Colina Limestone. Additional outcrops of Colina Limestone were found farther west along the northern margin of the limestone outcrops.

In one area, a white limestone was found in contact with the Colina outcrop. The rock has a fine rained white matrix containing small particles of calcite. The rock is considered by the author to be a component of the Colina Limestone.

Epitaph Formation

There are many exposures of light gray limestone which are devoid of chert and almost completely devoid of fossils. It is believed that these outcrops are those of the Epitaph Formation, which is partially a dolomite in some places. Small brachiopods were found in one exposure, but such occurrences are not common.

Near the north side of the large limestone ridge, on the north side of a moderate ravine, is a Forest Service signpost which shows the map of the long pipeline, being followed by the Arizona Trail at this location. Here, on the west side of the Trail, are three bands of interesting outcrops. The southernmost one is composed of a yellowish-gray rock about 2 meters wide. The northernmost one, which is essentially at the northernmost edge of the limestone rock, is a reddish tinged rock about 10 meters wide. The wider band, when observed carefully, is seen to consist of fragments tinted red in a matrix of lighter colored rock. A third band, about 1 meter wide, actually forms the boundary between the Paleozoic formations and the Triassic siltstones. This third band consists of thin, light gray to white beds, broken into fragments which are suspended in a matrix of darker siltstone or sandstone.

Similar or identical beds have been observed in the Lower Sawmill Canyon area, the Hilton Ridge area, and the Bells area, all of which represent a component of the Epitaph Formation. Both the relative elevation in the formation and the lithology appear to be essentially the same for all mapped areas. The basal beds appear to be thick bedded, light gray dolomite. Higher up are beds of broken and recemented rock. Above these are finely laminated, yellowish-gray dolomite. Above these thin beds are thicker beds containing clasts of various colors in a matrix of light colored limestone. At the very top are the thin rip-up clasts in a darker matrix.

Scherrer Formation

Immediately west of the Arizona Trail are large areas of a tan quartzite, which are obviously the Scherrer Formation. The stratigraphic column of Drewes' Plate 3 provides no hint as to what member it is, but the description given in Table 1 on page 5 of his text indicates that it is probably the "Lower quartzite and basal siltstone" member, which includes "quartzite, pale yellowish gray".

Toward the west, the northern and southern boundaries of the Epitaph Formation maintain a relatively constant separation, while the width of the Scherrer quartzite becomes progressively larger. As a result, the total width of the Epitaph outcrops diminish. The southern Epitaph exposure is limited to a relatively narrow band ranging between zero and 10 meters, while the northern Epitaph exposure does not exceed 55 meters. Between the two Epitaph beds. the Scherrer quartzite does not become less that about 135 meters.

Concha Limestone

The ellipsoidal chert nodules of the Colina near the crest of the ridge change into a black spongiform chert lying above highly fossiliferous limestone. In addition, two lenses of dark red chert over one meter long were found close to the fossiliferous area. Near the base of the hill near the eastern margin of the limestone are some limestone bodies which are associated with thick chert. Finally, west of the Arizona Trail are some medium gray limestones containing large Dictyoclustus fossils in a silicified condition. It is thought that all of these features are associated with the Concha Limestone, the uppermost Permian formation in this survey.

The presumed Concha outcrops west of the Arizona trail have been traced to the intersection of two faults, about 70 meters west of the Arizona Trail, where a small streamcourse crosses the Concha and Scherrer contact. It appears that the southern margin of the Epitaph beds occur a short distance north of the streamcourse and extends eastward. The contact of the Concha and Epitaph is somewhat gradational, in that the chert inclusions progressively diminish to the north. Thus, the position of the Epitaph-Concha contact is not easily defined. It is thought that the Concha outcrops begin at the fault offset where the small streamcourse crosses and extends east-southeast to the transverse fault between block 2 and block three. The Concha outcrops cover most of the southern part of Block 3.

The Concha chert is rather nondescript. It is generally brown or gray in color. Except for the silicified fossils found near its western boundary, the form of the chert is generally irregular, as irregular nodules, blocks, stringers, fragmented masses, or thin sheets. A few masses appear to show thin laminations.

The matrix limestone often occurs as separated masses, though larger and more contiguous masses occur. The smaller masses contain as few as one or no chert masses; larger limestone blocks may contain several more than a dozen chert masses as large as one's fist. The interior of the masses are often radically different than the chert surface, and in a number of cases have reverted to a clear or colorless silica. Because of the non-soluble nature of the chert, the masses generally project from the matrix limestone. In one case however, the silica was confined to a thin layer about 2 cm thick covering a fin-like projection of the interior limestone. the remainder of the fin projected about 1.5 cm to an irregular, apparently broken surface.

The color of the matrix limestone is generally somewhat darker than the lower Epitaph beds, with which they are in contact in some places. Higher Epitaph beds are distinctively colored, so they pose no problem as to identification.

Some of the outcrops are a darker gray limestone laced with a network of white fracture fills, probably calcite. This rock contains little or no chert, in contrast to most of the Concha outcrops. The boundary between the two rock types is somewhat irregular, suggesting a set of fault boundaries. The fracture-filled rock is possibly a component of the Epitaph Formation.

The contact of the cherty Concha with the primarily non-cherty Epitaph has been traced across the northern part of block 3 to the barbed-wire fence which is considered to be the western boundary of block 2. East of the fence, however, the outcrops are somewhat more difficult to trace on the northern side of the Tertiary gravel capping the hill. Most of the outcrops on the north side of the hill in block 2 appear to be cherty and are thus probably Concha.

The contact of the Epitaph and Concha, which occurs halfway up the north hillside, is a problem, as if cannot be readily traced. The contact has been tentatively extended eastward to the tentative extension of the transverse fault which is well exposed on the southern side of the ridge. It is assumed that the surface outcrop of the Epitaph is terminated at this fault trace and is not exposed again until it reappears again at the surface in block 1.

Some apparently non-cherty limestone exposures have been observed at various places on block 2, but there is no evidence to suggest a contact with the Epitaph beds at these places. Non-cherty beds considered to be Epitaph beds are exposed on the south side of the ridge, below the coarse gravel capping the ridge top. It may be that these beds extend beneath the gravel to a contact with Concha beds, in isolated areas exposed at the coarse gravel margin.

Gardner Canyon Formation

The Gardner Canyon Formation has been subdivided into two members, the upper member and the lower member. These two members have been further subdivided into a number of components based on their lithologies.Some of these lithologies are not found in the Apache Ridge area and thus are not considered here. From Plate 3, the lower member contains two thin limestone beds (one shown as marker bed a) and b, a sedimentary breccia. The upper member also contains two marker beds, conglomerate beds, dacite flows, and volcanic breccia. Of these, the latter three are not present in the mapped area and are not considered for this study.

Gardner Canyon Lower Member

The Gardner Canyon lower member consists of a tan siltstone containing two thin limestone beds. Inasmuch as the main emphasis of this study is the carbonates, little of the bounding upper and lower members have been surveyed. The primary area in which the Lower member has been surveyed is along the northern boundary of the Epitaph beds, in the western part of that contact. This area contains no limestone marker beds; thus none are shown.

Gardner Canyon Upper Member

The Gardner Canyon upper member consists primarily of a red, fine grained siltstone. The color of the upper member siltstone is brick red, which aids in its identification. The red siltstone is found in many places, including a reentrant of moderate size surrounding the water tanks at the eastern end of the map. In addition, outcrops of red siltstone are found up the small side canyon at the eastern end of the map, where several faults occur.

The Gardner Canyon upper member is in contact with about 3/4 of the primary limestone body shown on the geologic map of this study. One marker bed along the southern margin toward the eastern end of the limestone body has been surveyed and is shown on the map. The bed is of somewhat variable width, as shown on the map. The bed consists of a dark gray to black limestone, somewhat similar in color to the Colina Limestone.

The side canyon at the eastern end of the map eventually turns toward the northwest. Prior to this turn are some exposures of what appears to be light gray siltstone, which is probably a variant color of the upper member. Upper member siltstones farther south along the Arizona Trail exhibit a light green color.

The upper member also contains several other lithologies, which are exterior to the central area and not shown. A litharenite occurs along the Arizona Trail on the south side of the ridge crest and a bed of conglomerate occurs south of the ridge crest, east of the Arizona Trail and adjacent to the barbed wire fence. Outcrops of dacite are found farther away, primarily along lower Cave Canyon and Gardner Canyon.

Tertiary Terrace Gravel

The eastern end of the ridge slopes upward to a general level plateau covered with a very coarse, bouldery gravel of an unknown depth. The gravel is a remnant of coalesced alluvial fans derived from the erosion of the Santa Rita Mountains. The gravel eroded from this and other sites has been redeposited at lower altitudes in the form of Pleistocene terraces along Cave Creek and Sawmill Creek. The depth of the redeposited coarse gravel is generally one meter or greater. The tertiary gravel is denoted on profile views on Plate 3 as the "Pliocene Pediment". More recent studies refer to this surface as the Martinez surface.

In most places the exterior edges of the Paleozoic formations are lying in contact with the lower member of the Gardner Canyon Formation, except if the upper member has been emplaced by a fault. Exception to this general condition occurs where the Arizona Trail reaches the ridge crest on the south side. Here a sliver of what appears to be the upper member penetrates the limestone and extends some distance north. The sliver is poorly exposed and the exact boundary is difficult to precisely locate. This inlier is also shown on Plate 3 as a small triangular area.

The thin rip-up clast beds at the top of the Epitaph are, without known exception, in contact with the lower member of the Gardner Canyon Formation, generally a light tan siltstone. If the rip-up beds are the top of the Epitaph, it seems unlikely that there is an unconformity at the base of the lower member. In addition, at least one member of the Scherrer and at least part of the Concha Formations have been laid down since the end of Epitaph time.

Outcrops Of Uncertain Provenance

When surveying the northern side of the second structural block, a large outcrop was encountered, which was not limestone. The outcrop apparently consisted of two closely spaced masses or perhaps one mass with two projecting above the forest floor. The total width of the two masses was about two meters; the westernmost mass stood about one meter above the nominal forest floor. A small sample was removed and examined; it appeared to be a dark gray quartzite. A detached sample. possibly derived from the larger mass, was found to be a reddish-gray quartzite. One side exhibited slickensides, with a red overcoating on the grooved surfaces.

The two projections appear to be parts of a single mass. The mass seems too large to have been transported from alluvial fans derived from the Santa Rita Mountains to the west. The alluvial remnants which cap parts of Apache Ridge are generally limited to clasts no larger than a fraction of one meter in size. However, the possibility of stream transport cannot be ruled out.

Structure Of Apache Ridge

Faults:

Plate 3 of USGS Professional Paper 748 shows slightly diverging bands of Paleozoic formations spreading toward the southeast. The bands of Paleozoic rock are separated and flanked by Mesozoic rocks, primarily sedimentary but also containing some minor dacite flows, intrusives, and tuff (Drewes, 1972). The southernmost of the bands, an outcrop about 215 meters (700 feet) wide, contains primarily the Rainvalley Formation. North of this band is a second band about 600 meters (2000 feet) wide. This band splits into two components at about Cave Of The Bells, both of which trend in an east-southeast direction. The third, or middle band, extends from Cave Of The Bells along lower Sawmill Canyon and terminates just prior to the stream crossing of Forest Road 92. This short outcrop of Paleozoic limestone contains several small caves and one sink.

The northernmost band of Paleozoic outcrops continues to the eastern boundary of Plate 3, which is coincident with the eastern boundary of the Mt. Wrightson 15 minute map, the base map for this plate. Section B-B' of Plate 3 crosses the outcrops in a northeast direction. Both section B-B' and plotted strike/dip measurements show that the limestone beds in this northeastern band are dipping steeply northeast.

Geologic mapping by this author showed that both the trend of the outcrops and their attitude continued beyond the eastern border of Plate 3, up to a short distance past Apache Spring, where the limestone outcrops terminated. In general, strike/dip measurements average around 45 degrees dip, with a minor number of dips lower and higher than this average. These high dip angles confine the outcrops of the Permian rocks to a relatively narrow band between the bounding faults. Outside of the faults, the outcrops consist of the Gardner Canyon Formation, primarily the red siltstone of the upper member.

The bounding faults appear to be the primary structural features in the Apache Spring area, exhibiting the greatest displacement in a vertical direction. Transverse faults appear to cut across the bounding faults, offsetting the Permian formations. These secondary faults appear to exhibit only limited vertical displacement, but the actual displacement, either vertical or perpendicular to the bedding, is difficult to assess. One of these transverse faults, near Apache Spring, occurs between the first and second structural blocks, offsetting the first block to the south with respect to the second. The approximate surface trace of this fault can be discerned from the pattern of outcrops occurring along the fault, and from the apparent offset of the bounding faults on either side of the transverse fault. The apparent offset on the northern bounding fault is about 200 feet (60 meters); the offset on the southern side is indeterminate. Small offsets on the eastern side of Block 1 are well defined by the presence of the Gardner Canyon red siltstone.

The first structural block, the southernmost of several, extends southward to Forest Road FR-92. The southern boundary of this block is not known. as the south side of the road is grass covered, but a number of small limestone outcrops occur in the roadway.

The second structural block has been displaced about 140 meters north of Forest Road 92. The southern boundary of this block is not well defined because of the lack of outcrops toward its eastern end, but there are sufficient outcrops on the remainder of the western end of this bounding fault margin. A small transverse fault cuts this southern margin about 120 meters west from the transverse fault forming the eastern boundary, but it apparently does not extend across the entire block. This second block has a length of about 300 meters.

Surfaces of the second structural block are mostly covered with vegetation and talus on its lower slopes and the crest is covered by very coarse gravel on its summit, so that only the peripheral outcrop bands are visible. The northern side of Block 2 is covered primarily by the cherty outcrops of Concha Limestone, with a short remnant of Epitaph near its western boundary.

The second structural block is bordered on its western end by a third transverse fault, which runs along a barbed wire fence, The trace of this fault is lost near the crest of the hill at a cattle guard, and the remainder of the fault is tentative.

The third block is not strictly a structural block, although two transverse faults extend north along part of its western margin. The remainder of its margin is defined by the Arizona Trail. The block, defined in this manner is about 150 meters wide. A short segment of a transverse fault forms a 15 meter offset in the limestone along the southern margin of this block. The faulted limestone forms a small cliff which displays slickensides. the fault probably continues in a northeast direction, but limited exposures prevent tracing the fault farther north.

Two subparallel, apparently short faults, occur on the northern margin of the third structural block. One fault merely displaces the northern margin a short distance. The second fault, a short distance east of the first fault, completely truncates the upper, colored clastic beds of the Epitaph Beds and the thin, upper rip-up-clast bed. These two beds continue westward from the fault to the western end of Apache Ridge. In addition, these upper Epitaph beds are found on the Lower Sawmill Canyon map and the Cave Of The Bells map.

The easternmost 60 meters of the colored Epitaph beds and the thin rip-up-clast bed is separated from the adjacent limestone beds by an inlier of the Gardner Canyon upper member. The inlier must be fault bounded, but a lack of adequate outcrops in this area does not permit the identification of such a situation.

The fourth, westernmost structural area of this map extends westward from the Arizona Trail to slightly west of the Loop in the Forest Road 4085. The width of the Paleozoic outcrop area does not diminish appreciably, but the width of insoluble Scherrer Quartzite increases in a series of steps until it constitutes about 2/3 of the total band of Paleozoic rock. If the remaining 1/3, a narrow band of light gray rock. probably lower Epitaph, continues to the westward border of the map. The northern margin, consisting of the yellowish gray dolomite bed, the thicker red tinted clastic beds, and the thin rip-up-clast bed continue almost to the western margin of the map.

The wider Epitaph bed along the northern margin of the Paleozoic beds continues westward to what appears to be an inlier, possibly of the upper member of the Gardner Canyon Formation or as a remnant of the Tertiary terrace. The inlier is no more than 10 meters wide.

The small dry side canyon at the eastern end of the geologic map constitutes the approximate eastern end of identifiable outcrops. A short distance east of this canyon and north of Forest Road FR-92 is a slab of conglomerate about 2 meters long. The rock appears to be unconnected with any in-situ beds, but it may be a remnant. It resembles Cretaceous conglomerates found nearby in Cave Canyon.

The small structural block at the eastern end of the Apache Spring map shows that almost the entire area is covered by outcrops of limestone, except for a narrow band of the Gardner Canyon upper member siltstone. Two water tanks, one of which supplies water to Apache Spring Ranch, stand upon this outcrop band. The band extends from the eastern boundary almost to the western boundary of the first structural block. Thus, the positions of the insoluble formations, extending almost completely through the limestone, would provide only a narrow width of soluble limestone through which water could flow southward to Apache Spring.

Other Additional features

The small streamcourse which begins at a low causeway near the southern side of the limestone near the Arizona Trail, extends to the northeast, where it intersects a second stream near the limestone margin. The merged streamcourse turns east-northeast toward the margin. At about the place where the streamcourse would intersect the limestone (fault) margin, a small transverse fault offsets the margin a short distance northward. The stream and the limestone margin continue almost superimposed for almost 100 feet (30 meters) to a second transverse fault, which completely terminates the northern limestone, the band containing the reddish-tinted breccia and the rip-up-clasts.

The limestone bed is separated from a bed of what appears to be Concha Limestone by an inlier bounded by faults, The inlier extends back into the carbonates for about 30 meters.

Its composition is unknown within the inlier, but farther east The Gardner Canyon upper member is exposed on a steep creek bank. In the opposite direction, the reentrant appears to terminate at about the confluence of the two streamcourses.

A second reentrant consists of a window of apparently non-calcareous rock surrounded by limestone, just to the east of the Arizona Trail and nearer to the southern ridge crest. This area is about 70 feet (21 meters) wide by 230 feet (70 meters) long and is shown on Plate 3 near its eastern margin; however, the difference in scale reduces the depicted area on Plate 3 to an extremely small a area. A very small adjacent area is also shown; the color coding of that area possibly indicates an outcrop of Scherrer quartzite.

Anomalous Features.

A sequence of well exposed, identifiable beds occurs on the first fault block, from about the crest of the ridge, down toward the south. Beds at the ridge crest have been identified as Colina, with a narrow band of Concha just to the south and down the hill. This narrow band of Concha, only about 60 to 70 feet (20 meters) wide, is truncated on the south by what appears to be Epitaph outcrops, in a band even narrower than the Concha. On the south side of the Epitaph (?) band is an even narrower (15-20 feet) band of what appears to be Colina. The next lower outcrop, wider but less well exposed, appears to be Concha. This sequence of limestones is terminated on the south by an outcrop of red siltstone of the Gardner Canyon Formation upper member, upon which the water tanks stand.

There is no reasonable explanation for this sequence of limestones except to assume that they are fault slivers of the several formations represented. Furthermore, the red siltstone, an outcrop 80 to 100 feet (25 to 30 meters) wide, is bounded on the south by additional limestone. The extensive imbrication of the different formational slices, plus the termination of surface exposures of the entire Paleozoic column toward the east, implies a major transverse fault.

In the Tectonic Map Of Southeastern Arizona (1980), Drewes has projected the Sawmill Canyon Fault Zone southeastward across Sonoita Creek Valley to the Canelo Hills of eastern Santa Cruz County. He has not shown a range bounding fault along the eastern side of the Santa Rita Mountains. Presumably, the Paleozoic and Mesozoic rocks of the Santa Ritas have been progressively eroded downward toward Sonoita Creek or Cienega Creek and subsequently buried by alluvium washed down from the mountains. In any event, the limestone ridge north of Apache Spring has been downdropped east of the spring by a transverse fault, probably extending between southeastward trending faults of the Sawmill Canyon Fault Zone.

Geology Of Lower Sawmill Canyon - Introduction

Sawmill Creek is a small, normally dry streamcourse occurring primarily on the northern border of Santa Cruz County, Arizona. The upper reaches of the creek extend north into Pima County. The entire streamcourse and most of its small drainage basin is shown on the Mt. Wrightson 7.5 minute topographic quadrangle. The total length of the creek is only about 4.5 miles (about 7 km). The creek drains the eastern slope of the Santa Rita Mountains and continues eastward to join Cave Creek, a somewhat larger stream.

From the confluence, Cave Creek flows east less than 0.5 mile to the eastern margin of the Mt. Wrightson 7.5 minute topographic quadrangle map. The continuation of the stream is shown on the western edge of the Sonoita 7.5 minute topographic quadrangle, where it turns abruptly southward and joins Gardner Creek in about 0.4 mile. On the Sonoita quadrangle, the creek is termed Sawmill Creek, which appears to be incorrect. Sawmill Creek joins Cave Creek at a tee Junction, where Sawmill Creek abruptly terminates, but Cave Creek continues straight through the confluence. The total distance from Sawmill Creek to the Gardner Canyon confluence is about 0.9 mile, or slightly less than 1.5 km.

The geology of the northeastern part of the Mt. Wrightson 15 minute topographic quadrangle was surveyed by Harald Drewes and published as Plate 3 of USGS Professional Paper 748. This plate also covers the northeastern part of the Mt. Wrightson 7.5 minute quadrangle, which was published later. Plate 3 shows both the outcrops and structure of the mapped area as well as 5 sections, at a scale of 1000 feet per inch: the emphasis is on the structural relationships.

This author began surveying Lower Sawmill Canyon in the fall of 1999 as part of a study of the hydrology of this area. Drewes' Plate 3 was useful, but not sufficiently detailed for this study. Two years were spent in geologic mapping of the Sawmill Canyon area, extending from the Sawmill Creek-Cave Creek confluence on the east to the rhyolite dike (shown by Drewes) on the west. Additional surveying was conducted in 2003 on both the northwest and southwest parts of the map area to more fully depict the geology.

The surveyed area is roughly rectangular in the western two-thirds of its area and narrowing to a minimum on the eastern one-third. Sawmill Creek drains the central part of the mapped area where paleozoic carbonates outcrop; Mesozoic siltstones and marker beds (thin limestone bands) occupy areas peripheral to the central beds. In the western part of the mapped area, Sawmill Creek swings more towards the south, and the carbonate beds lie north of the creek. On the extreme northwestern side of the map, a complex area including siltstones, limestone marker beds, separate segments of a rhyolite dike, and several faults occur. The northern part of the mapped area is bounded by a Forest Service road, FR-4085, which heads northeast toward the margin of the Apache Ridge map.

Stratigraphy Of Lower Sawmill Canyon

Lower Sawmill Canyon is formed in part in carbonates of Permian age, while areas farther upstream and away from Sawmill Creek are formed in Triassic siltstone. The identity of the lowest outcrop is uncertain as it occurs over a very small area in the mouth of a small cave from which a dirt fill was excavated. This small outcrop, near the dug pit, may be from the Earp Formation, of late Pennsylvanian and early Permian age.

Colina Limestone

Much of the lower part of Sawmill Canyon is formed in the Colina Limestone of Lower Permian age. The rock is generally a dark gray to black in color, containing black chert. Near the top of the formation, the beds contain both a thin, tabular black chert and a nodular black chert. At a small cave not far from the lower end of the canyon, the limestone contains thin fissile beds, but these are a rarity. Certain horizons contain large gastropod fossils of the genus Omphalotrochus. In an adjacent study area, termed Apache Ridge, white limestone in contact with The Colina is thought to be a unit of the Colina, but no white limestone has been observed in this survey area.

Epitaph Formation

A short distance downstream from the small cave mentioned above are massive blocks of white dolomite which have fallen off the cliff above the cave. These blocks constitute the basal beds of the Epitaph. The formation is generally termed the Epitaph Dolomite but in this area the formation is a mixed dolomite and limestone.

Farther downstream, outcrops reveal both thinner dolomite and limestone interbedded. Higher on the hill, the formation contains broken clasts interbedded in a matrix. Above this horizon, at the level of a small foot trail, a thin series of yellowish gray beds consist of dolomite. Above the yellowish gray beds is a thicker sequence of broken clasts contained in a limestone matrix. Along the foot trail are areas where fracturing occurred but the broken blocks were not displaced; a bluish-gray staining occurs along the fractures, and some reddish coloration is also present.

At the very top of the formation is a thin (about 1 meter) bed containing broken thin fragments of white beds distributed in a darker silty matrix. This thin upper bed is essentially identical to beds exposed near the Arizona Trail along the northern edge of the limestone outcrops. The rip-up clasts indicate a shallow water condition, where beds were disturbed by storm activity.

The distinctive sequence of beds, beginning with massive dolomite at the base and extending up through a yellowish gray bed of dolomite to a generally colored, intraclastic sequence and a final thin rip-up layer is of much help in identifying the Epitaph beds.

The distinctive beds were useful in identifying the Epitaph beds on the north side of Sawmill Creek, at the extreme western end of limestone adjacent to Sawmill Creek. Here an area of rock about 10 meters wide by 45 meters long was positively identified as Epitaph, On the eastern end of the mapped area, the bed of Sawmill creek is covered with large rocks and boulders with the distinctive red tint diagnostic of the upper Epitaph beds.

No further Permian formations were recognized in the Lower Sawmill Canyon, including the Scherrer, Concha, and Rainvalley beds, which are encountered not far away in adjacent areas.

Gardner Canyon Formation (Triassic)

The Gardner Canyon Formation has been subdivided into two members by Drewes (PP748, page 5). The members have in turn been subdivided into components, including conglomerate, dacite flows, and volcanic breccia. In this report, those components will not be considered, as they do not occur in the study area. The remaining components which will be considered are the siltstones and the thin limestone marker beds contained in the siltstones.

Gardner Canyon Lower Member

The Gardner Canyon lower member in the study area consists almost entirely of a tan siltstone containing at least one thin limestone bed and some fragmentary limestone which has not been mapped. In addition, the lower member also contains quartz breccia (noted as sedimentary breccia) and thin white quartzite (not shown by Drewes but shown on my map). The lower member siltstone is in contact with most of the Permian limestones, except where it has been removed by faulting.

The thin limestone beds, (depicted as thin lines on Drewes' Plate 3), have been drawn to scale on the study map. These beds aid in determining the position of faults, which otherwise would be difficult to define. The thin beds are especially important in the very complex northwestern area of the map where complex faulting apparently has occurred.

The sedimentary breccia of the lower member (denoted by a "b" on the identifier, is found in small outcrops in several places. One occurs near the foot trail on the west side of a fault. A second occurrence occurs on the opposite side of the canyon, near what is believed to be the same fault. Two of the outcrops stand out as small pinnacles which are visible from the north side of the canyon; a third, larger outcrop is low and not readily visible. A fourth outcrop, not shown on Drewes' Plate 3, occurs a short distance north of the large elliptical deposit of Tertiary gravel, near the south margin of the large Epitaph outcrop.

In all of these cases, the rock identified by Drewes as a sedimentary breccia is a tan color, resembling tan chert. The large masses indicate that it is generally resistant to erosion.

The quartzite identified by this author in the south part is nominally white in color and occurs at scattered locations where weathering has not reduced it to rubble. In some cases, the presence of the quartzite aids in the identification of other features.

Gardner Canyon Upper Member

The Gardner Canyon upper member is generally brick-red in color but, in contrast with the lower member, can assume almost any color possible. One example of this color variety occurs at the confluence of Cave Canyon and Sawmill Canyon. There, thick beds of brick red siltstone contain a bed of light gray siltstone.

A smaller side canyon joins Sawmill Canyon near the western end of a long loop in Sawmill Creek. The canyon extends north, cutting through the limestone body to a tee junction. Two smaller dry streamcourses come to the tee from opposite sides. These two streams occur approximately at the contact of the upper and lower members. The upper member in this area is multicolored. In addition to the characteristic red beds, it exhibits thinner beds ranging from light gray to black, with beds of various intermediate colors.

A few thin beds exhibit a lithology different from the usual siltstone but constitute only a minor component of the upper member. Northwest of the tee junction, near the road, is a fairly thin bed of quartzite. Whereas the siltstone can be scratched with a sharp object, the quartzite is generally too hard to scratch. An orange quartzite occurs farther west, where FR-4085 turns east. Near the eastern end of the same valley and north of the road, the siltstone changes to a red sandstone with masses of white sandstone included inside the red sandstone. The total extent of these facies, on the margin of the surveyed area, was not determined.

On the extreme northwest part of the surveyed area, both upper and lower members and the thin limestone marker bed of the lower member are all mixed together in a confusing way. It appears that considerable deformation occurred in this area, so that a sequence of events will be difficult to unravel.

Tertiary Dike

A dike occurs near the western end of the area. The origin of the dike apparently is a batholith depicted on Drewes' Plate 3, on the south side of Cave Creek. Material from the batholith has apparently entered a fault fracture and moved northeast across Sawmill Creek, and ultimately extending to the Epitaph margin. Drewes shows the dike as a uniformly narrow body along its entire length, but the narrow width is not uniformly typical. The dike, mapped by this author, was of variable width and direction. In a number of places, the dike was intermittent and a number of gaps were apparent. In a few places, isolated outcrops of dike material appear to have been displaced by faults, and a few small pieces of dike material appear some distance away.

One larger area, off to one side, appeared as if it might have been a small sill of the dike material exposed by erosion, as its width was appreciably larger.

In all cases, the dike material exposed from near Sawmill Creek north to its terminus consisted of a light gray groundmass with small phenocrysts in some cases. The material appears to weather somewhat more rapidly than limestone and is reduced to fragments by weathering. The resistance to weathering is somewhat variable, with some outcrops reduced to ground level and some protruding from the ground. South, near Onyx Hill, some parts of the dike project more than one meter above ground level.

The age of the dike material is given by Drewes on plate 3 is 26 Ma from the potassium-argon method and 40 Ma by the lead-alpha method. Further information about the age of the dike may be available at this time, some 32 years after publication of PP748.

Tertiary Gravel

A large diameter but probably not very thick deposit of coarse Tertiary gravel washed down from the Santa Rita Mountains covers the crest of the hill in the western part of the map. Much of the coarse gravel covering the underlying rock was washed away by Pleistocene erosion; Remnants of the gravel now occur in terraces bordering Sawmill Creek and Cave Creek. Profiles of the gravel on Drewes' Plate 3 are termed the Pliocene Pediment, of which most has been eroded in this area, leaving a hypothetical surface.

Pleistocene Terraces

Lower terraces, formed both by erosion and deposition of the reworked Pliocene Pediment gravel, are found along Sawmill Creek, Cave Creek, and Gardner Creek, to which the former two streams are tributaries. A single terrace, about 10 meters above the present stream, is the single prominent Pleistocene terrace on this study area. The four terrace segments along Sawmill Creek are younger, probably of Holocene age.

Mineral Deposits

There are not many mineral deposits occurring in the Lower Sawmill Canyon area. A few seams of what appear to limonite occur below the foot trail. A deposit of massive crystalline calcite occurs north near the crest of the ridge above the western end of the foot trail, possibly resulting from the discharge of calcite-bearing water. Some large euhedral crystals of quartz have been found on the south side of Sawmill Creek, after apparently having formed in cavities in the lower member siltstone and later exposed by erosion. The quartz may be the result of hydrothermal solutions associated with the igneous dike.

The Structure Of Lower Sawmill Canyon

The geologic structure of Lower Sawmill Canyon has been displayed in both the geologic map of Plate 3 and selected profiles applicable to cross sections taken on that map. Those structural features generally agree with the structural elements defined by this authors' surveys, but not completely,

One of the primary structural elements shown on Plate 3 is an anticlinal fold roughly coincident with the axis of Sawmill Creek in its lower reaches. Additional features are three faults, more or less parallel to each other and oriented in a north-northeast direction. The first two of Drewes' faults correspond to faults shown of this authors' map, but a third could not be verified. That fault is approximately coincident with the side canyon which joins Sawmill Creek near the center of the author's map.

On the other hand, the two faults which correspond to the faults shown on Plate 3 and additional other faults not shown are depicted in much greater detail, in part because of this author's scale factor: 100 feet per inch. Several methods have been used to delineate the faults. The primary method depends on abrupt offsets of formational contacts or offsets of marker beds. In two cases, the actual fault contact is visible. In those cases, denoted with the letter "f", beds on opposite sides of the fault slope toward one another and meet at a roughly vertical fault plane.

An interesting structural situation occurred on the north side of the hill north of the foot trail, near the crest of the hill where two closely spaced marker beds and two similar beds farther down the hill occurred. Dip measurements revealed that the uppermost two beds were dipping at angles slightly less than the slope of the hill, while the lower two were dipping at angles greater than the dip of the beds. It was evident that these lower beds were the same ones observed near the crest of the hill. The beds emerging at the crest of the hill had been eroded away down to the place where the uneroded beds dived beneath the hillside.

Fault planes appear to be essentially buried on the west side of the large Tertiary gravel area. There, the gravel is apparently thin, allowing occasional exposures of the red siltstone of the Gardner Canyon upper member. The structure in this area is rather complex, and the postulated fault is tentative. A second fault is postulated to intersect the first at a sharp vertex. One of these faults could continue for a distance past the intersection, but there is no definite evidence that such a condition exists,

West of the Tertiary gravel is an area where both the Gardner Canyon lower member marker bed and the Tertiary dike are present. It appears that the only way in which these two features could be displaced in a logical manner is for initial displacement of the marker bed along a fault (shown), injection of the dike, and then subsequent reversal of the fault movement, displacing both the dike and the marker bed to cause the final relationship of the two.

As noted previously, it appears that the dike formed a sill along one side of the fault carrying the dike material. The sill apparently formed a cavity 50 meters long at the side of the dike, but some of this length may be downhill float of weathered dike material, rather than actual outcrops.

The dike continues, with some gaps, northward through Epitaph rock and appears to terminate at the contact of the Epitaph and the Gardner Canyon lower member. No trace of dike material was found north of the contact. It is possible that the fault injected by the dike terminated at the contact, or that the pressure in the dike was relieved by a breakout at the sill.

The dike has been traced, with some interruptions, across Sawmill Creek. The dike is not visible on the terrace north of the creek, presumably because the terrace was covered by alluvium at the end of a depositional phase. The trace of the dike can be found on the north creek bank and south of the creek in several places. A continuation of the dike was surveyed for the map of Onyx Hill.

Slickensides, though not prevalent, do occur in a few places. Several observed exposures occur at the entrance of the small cave which opens at the base of a cliff, about 3 meters above the creek bed. Low angle slickensides, perhaps indicative of thrust faulting, occur on the exposed upper side of the sedimentary breccia which is exposed a short distance north of the Tertiary Gravel deposit. An obvious slickenside is exposed on The red upper member siltstone on the south side of Sawmill Creek, near the place where the Tertiary dike crosses Sawmill Creek.

The anticlinal fold noted by Drewes on Plate 3 of PP748 has an axis which is generally south of Sawmill Creek. At the foot trail on the north side of the creek, the dip is about 20 degrees to the north; the dip increases toward the north and reaches at least 45 degrees in the small valley north of the creek.

Small faults have been observed on the anticlinal fold, with dips much steeper than the nominal fold dip and strikes not in concordance with the fold dip directions. A number of faults have been noted in the small caves found in this area, all of which formed prior to solutional development of the caves,

A feature which is the possible result of both lithologic and structural origin occurs along the foot trail not far from its origin at the eastern margin of the map, The feature is a sink of apparent natural origin developed in the insoluble lower member of Gardner Canyon siltstone. The sink looks as if it were cut down into the hill, starting at ground level and deepening into the hillside. There is no evidence of human intervention and the sink appears to be natural. The sink appears to have a drain at its low side which leads down into one of the thin marker beds. The water entering this apparent drain may make its way to a small resurgence on Cave Creek, a short distance downstream from the confluence of Cave Creek and Sawmill Creek.

A similar feature, though not natural, is an apparent excavation on the south side of Sawmill Creek, a short distance upstream from the confluence of the small side canyon with Sawmill Creek. The excavation occurs at the margin where the low terrace joins the sloping hillside. The hole is about 2 meters deep.

Inliers and Windows

An inlier is a relatively long and narrow outcrop extending into another different formation. A window is an outcrop of one formation completely surrounded by another formation. On the south side of Sawmill Canyon, the contact between the upper and lower members of the Gardner Canyon Formation extends generally eastward from a beginning near Sawmill Creek, following a somewhat irregular path, with the upper member lying south of the lower member. At a distance of about 200 meters from the western origin , the contact makes an abrupt turn to the left, at about a right angle to its original orientation, and extends northwest for about 18 meters. The contact then turns 90 degrees to the right and extends toward the northeast for about 11 meters. At this third point, it turns right again and heads in a southeast direction. At a point near the first turn, it turns left and heads northeast, in a direction about the same as its original orientation.

The result of these turns and displacements is that a narrow extension of the upper member has been intruded into the lower member. It appears that the displacement has occurred along a set of closely spaced subparallel faults, with a total displacement of about 18 meters.

A somewhat similar situation has occurred farther west at about the western end of the same contact between the upper and lower members. In this case, however, a narrow outcrop of the lower member about 30 meters long has been completely surrounded by both the Colina and Epitaph formations in fault contact.

An apparent second presence of a window occurs toward the northwest, on the north side of the large Tertiary Gravel deposit. Here, a somewhat irregular body of Colina Limestone. about 30 meters across, is surrounded on two of its three sides by the Epitaph Formation. The third side is obscured by hillside alluvium, but the alluvium probably covers the Epitaph Formation. This rather small body of rock exhibits several discordant strike and dip readings, implying some internal deformation.

The Northwest Structural Area

The Northwest Structural Area of the Lower Sawmill Canyon is rather complex. the area is covered by sizable areas of both the upper and lower members of the Gardner Canyon Formation. There, identification is in places hampered by vegetation and overlying rubble. In addition to the Tertiary dike, the area exhibits many narrow beds of white limestone, believed to be marker beds of the lower member.

On the adjacent Apache Ridge geologic area, the marker beds in the nominally red siltstone of the upper member tend to be dark gray to black in color, with tinges of dark red in places. None of the marker beds in the Lower Sawmill Creek area exhibit this dark coloration. The dike material is also light colored but can be readily distinguished from the Gardner Canyon limestones.

The white limestone marker beds exhibit a confusing relationship with one another, in that they appear to join in triple junctions. Simple erosional dissection of a siltstone bed containing a thin limestone would most likely produce a narrow, linear limestone outcrop. Triple junctions could seemingly result only if thin imbricated beds eroded to produce superimposed marker beds at the surface.

It is possible that the apparent triple junctions are really only a mistaken evaluation of the true situation. The limestone marker beds are generally fragmentary, either as the result of actual complex faulting or the result of inadequate exposure. The separated limestone blocks have been shown as a thin contiguous bed for convenience, but a different interpretation might be possible.

The structure southwest of the confluence of the small side canyon with Sawmill Creek is somewhat enigmatic because it is primarily hidden by alluvium on both sides of Sawmill Creek. Drewes' Plate 3 shows a fault trending west-northwest beneath a terrace, which probably is the terrace north of Sawmill Creek, but Details on Plate 3 are insufficient to determine the placement of the fault.

Mineralization

No mineralization has been noted in the Lower Sawmill Canyon area, except for the few masses of crystalline calcite and a few small masses of limonite below the foot trail. The sink-like hole on the south side of Sawmill Creek appears to be man-made and probably was a test pit. No trace of any mineralization was observed at the test pit.

Some fairly large (up to 10 cm long) euhedral quartz crystals have been found on the Gardner Canyon lower member on the south side of Sawmill Creek, a short distance south of the limestone. The crystals appear to have formed in cavities in the siltstone, which were later breached by weathering. The largest crystal has several small inclusions of siltstone where the crystal touched the walls of the cavity in which it formed. The crystals are white, rather than transparent. This defect is probably the result of surface weathering during the time when the crystal was exposed.

Geology Of Resurgance Area On Cave Creek

Introduction

The area studied in this report occurs near the confluence of Cave Creek and Sawmill Creek. Within the limits of the study, only two formations are exposed. The lower of the two is the Epitaph Formation, commonly termed the Epitaph Dolomite, of lower Permian age. The underlying Colina Limestone, also of Permian age, is not exposed here, although it outcrops nearby. The second formation is the Gardner Canyon Formation of Triassic age. It is subdivided into several members, two of which are considered here. The lower of the two members, a tan siltstone, contains a thin, nominally white limestone occurring near the top of the member. The upper member is nominally a red siltstone. It also contains thin limestone marker beds, but these beds are not exposed within this study area.

The resurgence area occurs on Cave Creek, only about 100 meters east of the confluence of Sawmill Creek and Cave Creek. There are actually two resurgences present, at least in times of wetter weather. The primary resurgence is essentially a wide seep at the base of a low ledge; the secondary resurgence is also a seep about 27 meters upstream. The primary resurgence comes out on top of a low platform of mud only about 15 cm above the normal stream elevation, and the secondary resurgence is even lower. Both of the resurgences are obscured when there is even a slight rise of water in the creek.

On Plate 3 of USGS Professional Paper 748, Drewes shows a fault extending eastward along Cave Creek at this location, with the upper member of the Gardner Canyon Formation, a generally red siltstone, exposed on the south side of the creek. The Gardner Canyon lower member is shown on the north side of the fault.

The lower member is apparently less resistant to erosion, and that outcrop is somewhat obscured on the north side of the creek, which is forested and partially covered with talus. Narrow outcrops of white limestone, a marker bed in the lower member,are exposed on the northern side of the streambed and partway up the side of the sloping canyon wall farther downstream, near the Forest Service gate. Scattered outcrops of the white limestone occur near the resurgences.

A short distance downstream from the Forest Service gate, the incidence of the forested slope on the north side of the canyon abruptly ends, apparently as the result of a fault, and the red outcrops of the upper member extend completely across the canyon. The lower tan siltstone and the marker bed do not occur here; in fact, those outcrops occur about 75 meters north of their previous position. At this location, the exposed limestone bed occurs in the top of the terrace bordering Cave Creek, at least 10 meters above the bed of the creek. It is obvious that the groundwater has emerged at a place as low as possible, as far downstream as soluble beds will allow a resurgence.

Groundwater in the Colina and Epitaph carbonates occurs in the downdipping beds, which lie beneath the siltstones exposed at the resurgences. Apparently these thicker beds are somehow in contact with the thin limestone bed of the lower member. so that the water can rise through the limestone to the resurgences. The large sink opening on the eastern side of Sawmill Canyon is only about 140 meters from the upstream resurgence (Note traverse "A" on map). A probable profile view is shown in Figure 4, in which the thin marker bed is thrust into contact with the Epitaph beds within the distorted beds along the fault.

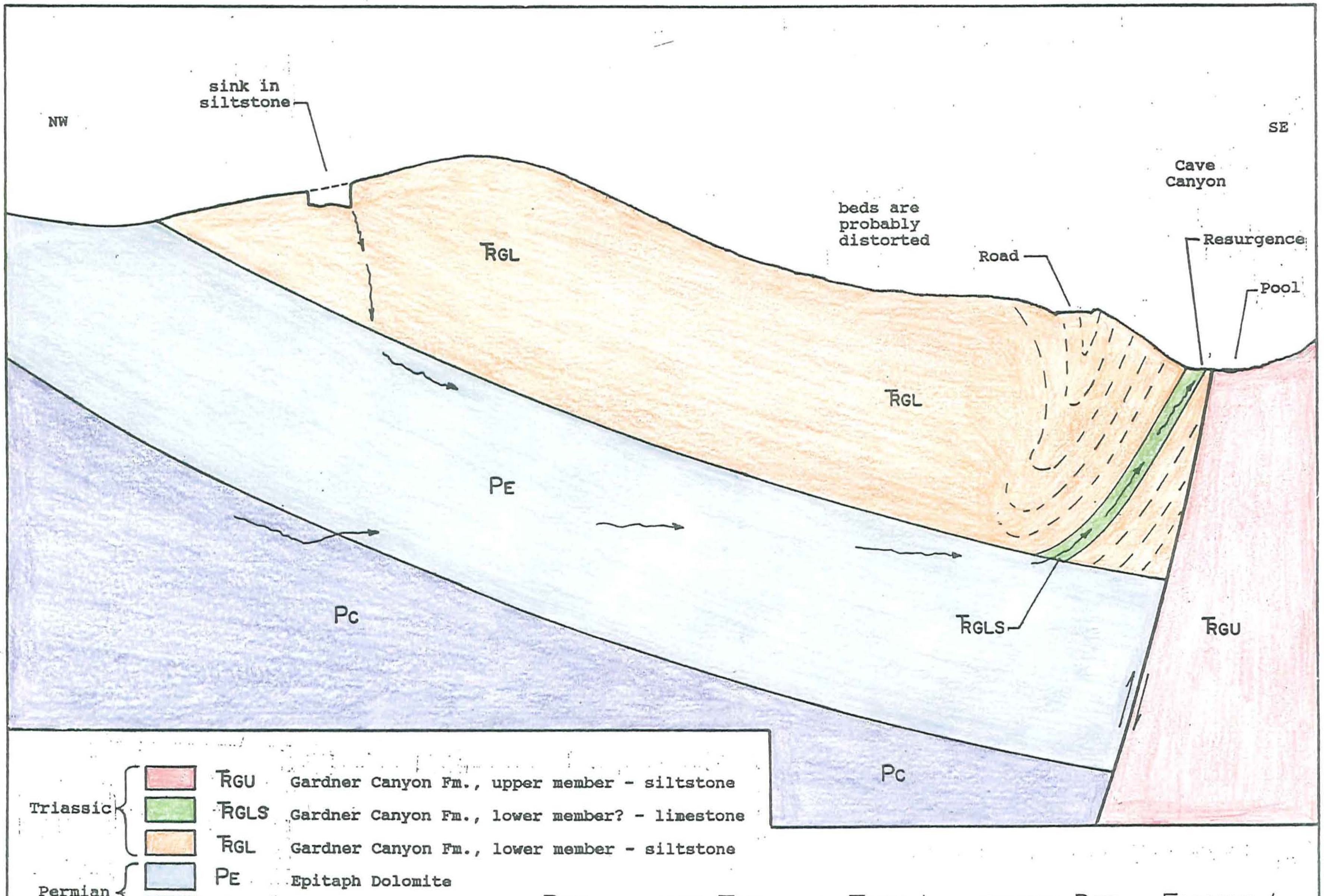
Lower Sawmill Creek, developed in the Colina and Epitaph Formations, was found to be a sinking stream. Observations made during December 2000 showed that water in Sawmill Creek sank into the stream bed at places progressively upstream, despite continuous though diminishing flow upstream. Finally, on December 28, the lower end of Sawmill Creek (in limestone) was completely dry almost all the way upstream (Figure 5) to the siltstone, where the creek was still flowing. The pirated water must obviously resurge not far away from the end of soluble rock.

Another probable source of groundwater is Cave Of The Bells, which occurs about 1460 meters upstream and contains pools of water about 80 meters below the entrance. An evaluation of the various altitudes nearby indicates that the resurgence for the cave had to be at least this far away to drain the cave.

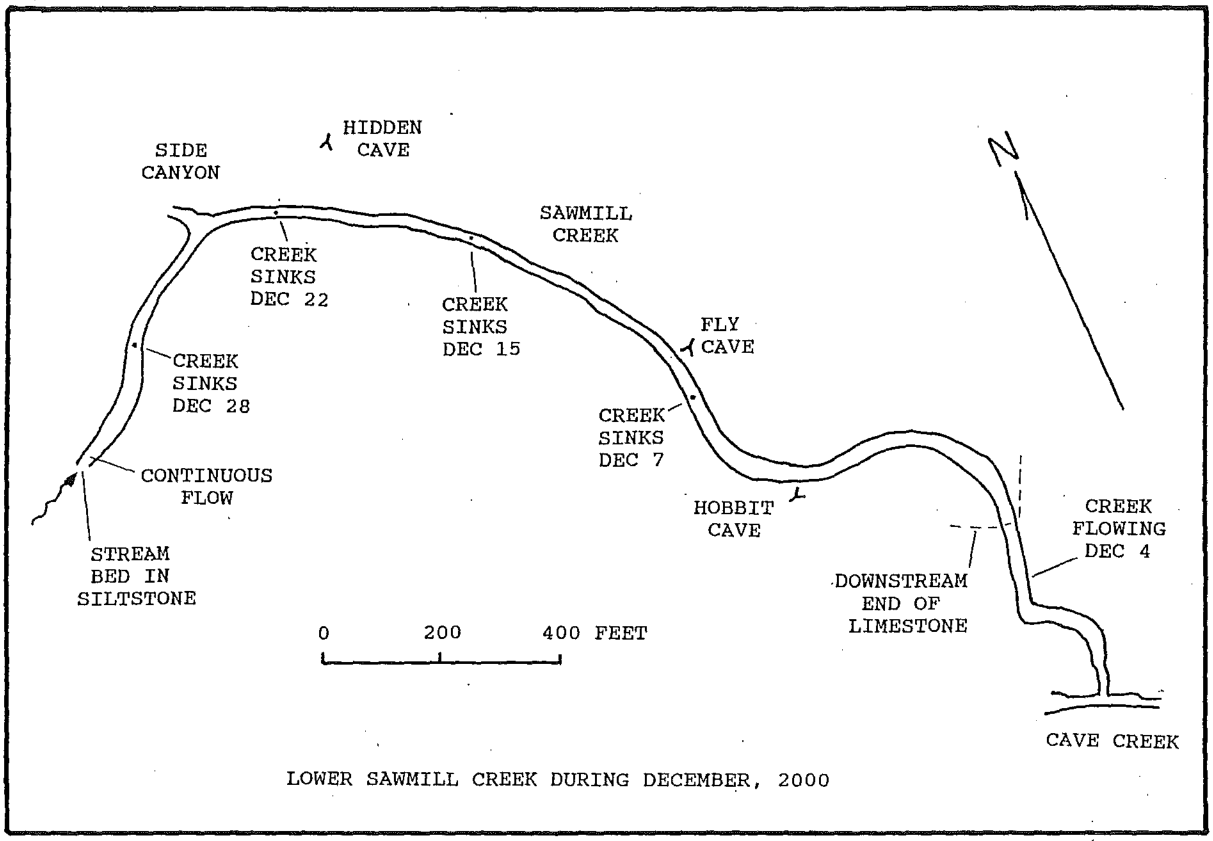
At one time it was thought that Onyx Cave might be the source of the water rising at the Cave Creek resurgences. However, careful examination of profile B-B′ on Plate 3 of PP748 shows that there is no way that this source is connected with the resurgences. Another possibility is the lateral movement of groundwater through Colina Limestone from the north. However, on the basis of the Apache Ridge survey, it is likely that such groundwater would drain to Apache Spring.

It is known from surface observations that the groundwater rising at the Cave Creek resurgences is almost certainly rising through the thin Triassic limestone of the Gardner Canyon lower member. This bed is not well exposed but one measurement taken about 50 meters downstream from the major rise shows a dip of 36 degrees to the south. Several hypothetical profiles have been constructed, one of which is shown a connection between the Epitaph limestone beds and the thin lower member limestone.

The contact between the upper and lower members is also not well known, despite the fact that these beds are moderately well exposed on the creek bed. The problem is that there are several beds near the somewhat obscure fault which seem to be transitional and which may be components of the lower member. Even the thin bed of limestone through which the water rises is only sporadically visible between the confluence and the downstream cross fault.



RESURGENCE THROUGH THIN LIMESTONE BED FIGURE 4



SINKING STREAM IN LOWER SAWMILL CANYON FIGURE 5

Geology Of Hilton Ridge

Introduction

Hilton Ridge occurs in the northeastern part of Santa Cruz County, Arizona, about 30 miles southeast of Tucson, as shown on the location map. Figure 1. The local area is shown on the Mt. Wrightson 7.5 minute topographic quadrangle map. Hilton Ridge is the informal name for a low ridge lying between Sawmill Creek on the south and Forest Road 4086 on the north. The southeastern boundary is on a saddle occupied by Forest Road 4085, and the northwestern boundary is arbitrary, being essentially defined by the northwest end of Permian outcrops.

The survey area includes both the central ridge area and some surrounding areas. The central ridge is bounded on the south and southwest by Sawmill Creek and a short, generally dry tributary lying along the southwest flank of the ridge. The eastern end of the ridge is cut by a small, normally dry streamcourse coming past the Cave Of The Bells area to the northwest.

The primary geologic feature of Hilton Ridge is a somewhat ellipsoidal window of Epitaph Dolomite, which is shown on Plate 3 of USGS Professional Paper 748 (Drewes, 1972). The outcrop shown is about 300 meters long and 60 meters wide, slightly curved. It is bounded by siltstones of the Gardner Canyon Formation on all sides. The map provided in this report is slightly more angular and much more detailed, showing features which were too small to be shown on Drewes' Plate 3.

A primary feature of interest within the bounds of the study area is a small cave with the name of Hiltons Hole. The cave has a single vertical entrance about 1.5 m long at the bottom of a small sink not much larger than the entrance. A climbable descent of 6 meters allows access to a fairly level flooor. The cave consists of two rooms with a total combined length of about 25 meters.

After surveying the periphery of the Epitaph outcrop area, it was found that the area had an essentially triangular shape with the largest width, about 75 meters, on the southeast. The outcrop area, after a central section of relatively constant width, tapered to almost a point on the northwest. A narrower extension on the southeast end brought the total length of the Epitaph outcrop area to about 335 meters.

The area is generally well exposed; bedrock outcrops cover large areas, and areas covered by vegetation are small. Alluvium is minimal and is primarily limited to a small area on the southeast. The ridge is lightly forested, primarily on the carbonate outcrops. The low ridge, of which Hilton Ridge is the southeastern terminus, continues west-northwest, past the Cave Of The Bells area, which is part of the same low ridge, but there termed Bells Ridge.

Stratigraphy of Hilton Ridge

Colina Limestone

The primary, central exposure on Hilton Ridge is the Epitaph Dolomite, as shown by Drewes on Plate 3 of USGS Professional Paper 748. In this general area, the Epitaph is underlain by the Colina Limestone, which is not exposed on Hilton Ridge, but which is exposed in surface outcrops not far away. The measured thickness of the Epitaph in the Lower Sawmill Canyon area is about 100 feet; the depth of the upper surface of the Colina Limestone is probably no greater than that measured thickness and may be less.

Epitaph Formation

The Epitaph Formation is generally termed the Epitaph Dolomite because of the presence of dolomite beds in the formation. In this specific area, the formation contains much limestone, so the author has used the term Formation for this specific area. In Professional Paper 748, page 5, Drewes has subdivided the formation into two members. The upper member is listed as Limestone, moderately thick bedded, medium gray, slightly cherty, with a nominal thickness of 380 feet (115 meters).

The lower member of the Epitaph Dolomite, as listed by Drewes, contains light-brownish-gray marlstone, dolomitic siltstone, gypsum and argillite, and dark to medium gray dolomite, with a nominal thickness of 620 feet (189 meters). None of these lithologies have been recognized in any of the geologic areas mapped by this author. On Plate 3, Drewes also includes a non-specific block designated only by the symbol Pe.

The Epitaph outcrops surveyed by this author have contained some dolomite but also contain what appears to be a majority of limestone, some of which is fractured or brecciated. Some of the fracture fragments are colored, especially in the Apache Ridge and the Lower Sawmill Canyon mapped area. Similar fracture fragments occur in the Hilton Ridge and the Cave Of The Bells mapped areas but without the more diagnostic coloration. The Epitaph observed on Hilton Ridge has been termed the Epitaph Formation for this reason.

Scherrer Formation

On Plate 3, Drewes shows that the Scherrer Formation has been subdivided into four members, an upper Quartzite member, a middle dolomite member, a lower quartzite member, and a basal siltstone member. A very small outcrop of what is believed to be the lower quartzite member has been found on Hilton Ridge, close to the entrance of the small cave. On page 5 of PP748, Drewes briefly describes the lower member as "quartzite, pale yellowish gray", a description which matches that of the small outcrop near the cave. No other outcrops of the Scherrer Formation are known to occur either on Hilton Ridge or on the adjacent Cave Of The Bells area. However, careful reconnaissance was not conducted far beyond the map bounds; other formations may be present.

Concha Limestone, Rainvalley Formation

Although the Concha Limestone and the Rainvalley Formation occur in the general vicinity, no trace of them has been found on Hilton Ridge.

Gardner Canyon Formation Lower Member

The elongated Epitaph outcrop area is surrounded by the upper and lower members of the Gardner Canyon Formation of Triassic age, both primarily siltstones. The lower member is adjacent to the Epitaph outcrop on all sides, except for the extreme southeast, where the lower member seems to be covered by an alluvial terrace. Within much of the southwestern exposure of the lower member is a thin bed of light colored limestone, defined by Drewes as a marker bed. The bed is not present in the southeastern extremity of the lower member, an area where the lower member is rather narrow.

A short distance north of the Epitaph margin is a small outcrop of limestone, either a displaced fragment of the Epitaph or an inclusion of Triassic limestone. In a few places the white mass is in contact with a red inclusion. The identity is unknown.

Gardner Canyon Formation Upper Member

The lower member is bounded on the south and southwest by the upper member of the Gardner Canyon upper member, primarily a deep red siltstone, grading into a red sandstone in a few places. An area on the southeast is covered with alluvium, but it is almost certainly underlain by the upper member. A short distance to the south is Sawmill Creek, which flows in a shallow trench cut in the upper member.

Pleistocene Terraces

Cut banks along Sawmill Creek and a small dry tributary show a sectional view of a probably Pleistocene terrace deposit composed of coarse gravel and overlain by a finer silt. The coarse gravel is derived from the older Tertiary Martinez surface, the coalesced alluvial fans derived from weathering of the Santa Rita Mountains. The surface of this gravel has been termed the Pliocene Pediment by Drewes and noted on Plate 3 of Professional Paper 748.

Other small areas are covered by recent alluvium derived from the higher parts of the adjacent hill. Other alluvial areas are found along the small streamcourse flowing southward along the east margin of the study area, adjacent to and crossing FR-4085.

During surveying, three small areas of massive crystalline calcite were found and noted on the map. The calcite is thought to have been deposited by hot water seeps which once surfaced here. The calcite is massive and shows no crystal faces, although such surfaces may have exposed prior to weathering. The calcite occurs near fault traces.

Structure of Hilton Ridge

Drewes shows the southern margin of the Epitaph outcrop to be bounded by faults, which is partly correct. The southern margin of the Epitaph outcrop is bounded by the Gardner Canyon lower member along its entire length, although the outcrop width is quite narrow for a short distance near the southeast end.

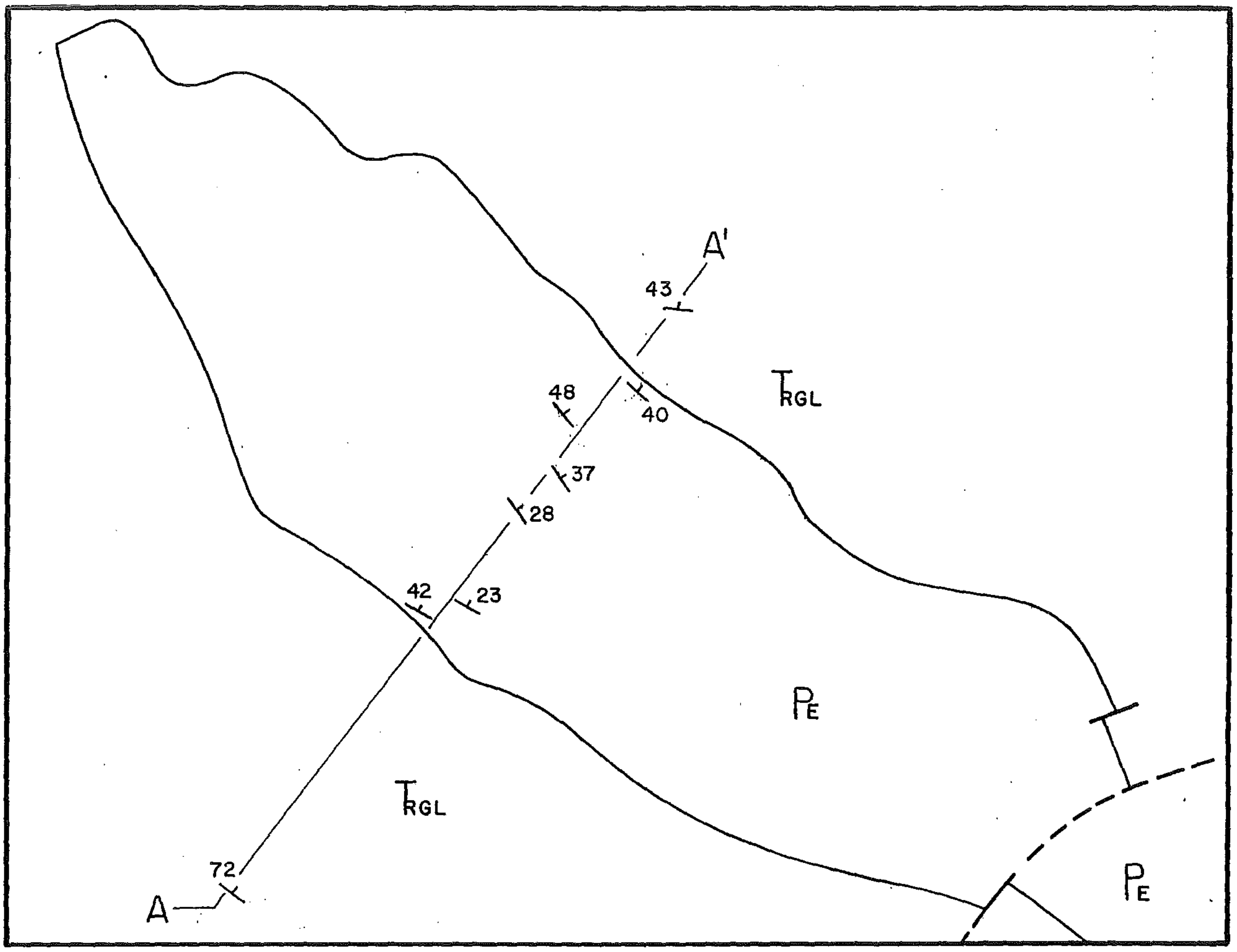
The northern margin of the Epitaph body is, however, bounded by a fault which extends westward for about 100 meters and then turns toward the southwest and finally almost south, extending through the Epitaph body and continuing beyond. In addition to visible outcrops along the fault, it displaces a limestone marker bed by about 22 meters. Finally, the fault and a nearby parallel fault segment enclose an inlier of the upper member so that it projects 15 meters into the lower member. Interestingly, the three calcite bodies occur near the main fault and a short fault segment 9 meters northwest of the main fault.

The northern margin of the lower member is thought to extend linearly past the second (inlier) fault, but the tentative margin is covered with alluvium. The tentative margin is apparently displaced 10 meters to the north by a short, somewhat curved fault occurring 45 meters east-southeast of the second (inlier) fault.

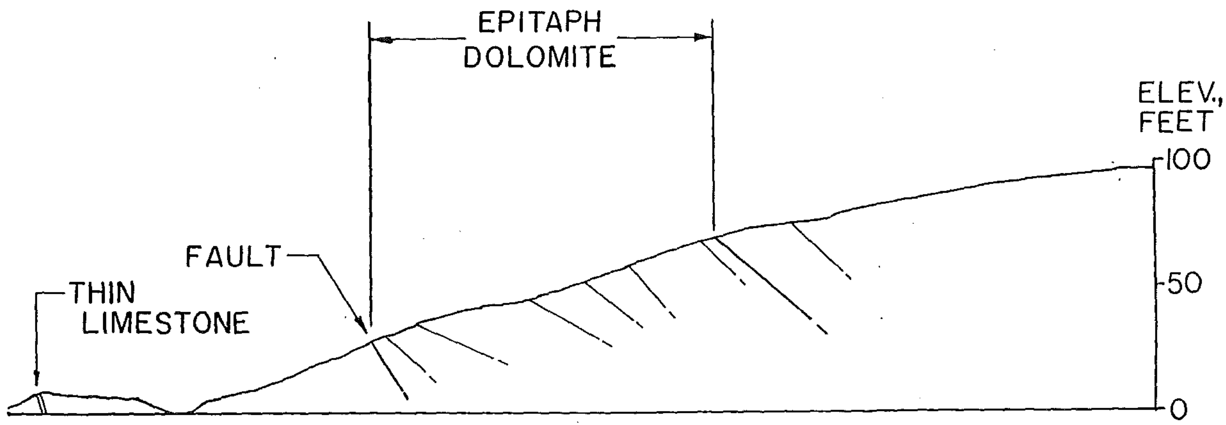
The eastern margin of the Epitaph body is a somewhat curved fault which extends almost to the southern margin. A small offset to the east is apparently defined by several small fault segments. Near the northern end of the curved fault, the small streamcourse flowing from the north curves to the west and then makes an abrupt turn to the south, Past this turn, the stream flows along a low cliff, which appears to be formed in the lower dolomitic beds of the formation. Two thrust faults are exposed in this cliff, with dips of 11 and 21 degree. The northwest end of the Epitaph outcrop body also appears to be truncated by a fault striking northeast. The dip, measured on exposed rock adjacent to the fault, is 56 degrees southwest.

On plate 3, Drewes shows an anticlinal fold extending almost the entire length of the Epitaph outcrop. To check this portrayal, a traverse was surveyed across the entire outcrop in its northwest part, extending beyond the Epitaph on both sides (Fig. 6). Despite some minor changes in dip angle, the dip direction always pointed northeast, as shown in Fig. 7. Thus, the portrayal of an anticlinal fold appears to be an error.

In the southwest part of this geologic map, the limestone marker bed in the Gardner Canyon lower member is missing over a length of about 14 meters; the presence of a fault is suspected. Toward the southwest, the contact between the upper and lower members is obscured. Along this same direction, there is a large offset in the axis of the small dry streamcourse. Northeast along this same axis, the contact of the lower member with the Epitaph body is indistinct. These omissions may indicate a hidden fault.



STRIKE AND DIP ACROSS ACROSS NW HILTON RIDGE FIGURE 6



DIP ANGLES ON TRAVERSE, NORTHWEST HILTON RIDGE

FIGURE 7

Cryptic Outcrops and Structure on Hilton Ridge

While examining the surficial geology in the southeastern part of the Epitaph outcrop body, a number of anomalous outcrops were observed. Careful study revealed that these were outcrops of the Gardner Canyon lower member siltstones. The indistinct outlines were so obscure and irregular it was necessary to survey them at a scale of 10 feet per inch (120:1), in contrast to the normally used scale of 50 feet per inch (600:1), over a rectangular area of 90 by 160 feet (27 by 49 meters). The map thus prepared (Fig. 8) showed that the siltstone was exposed over an irregular area surrounded by outcrops of the Epitaph Formation. The opening to Hiltons Hole was in the western end of the enlarged map area.

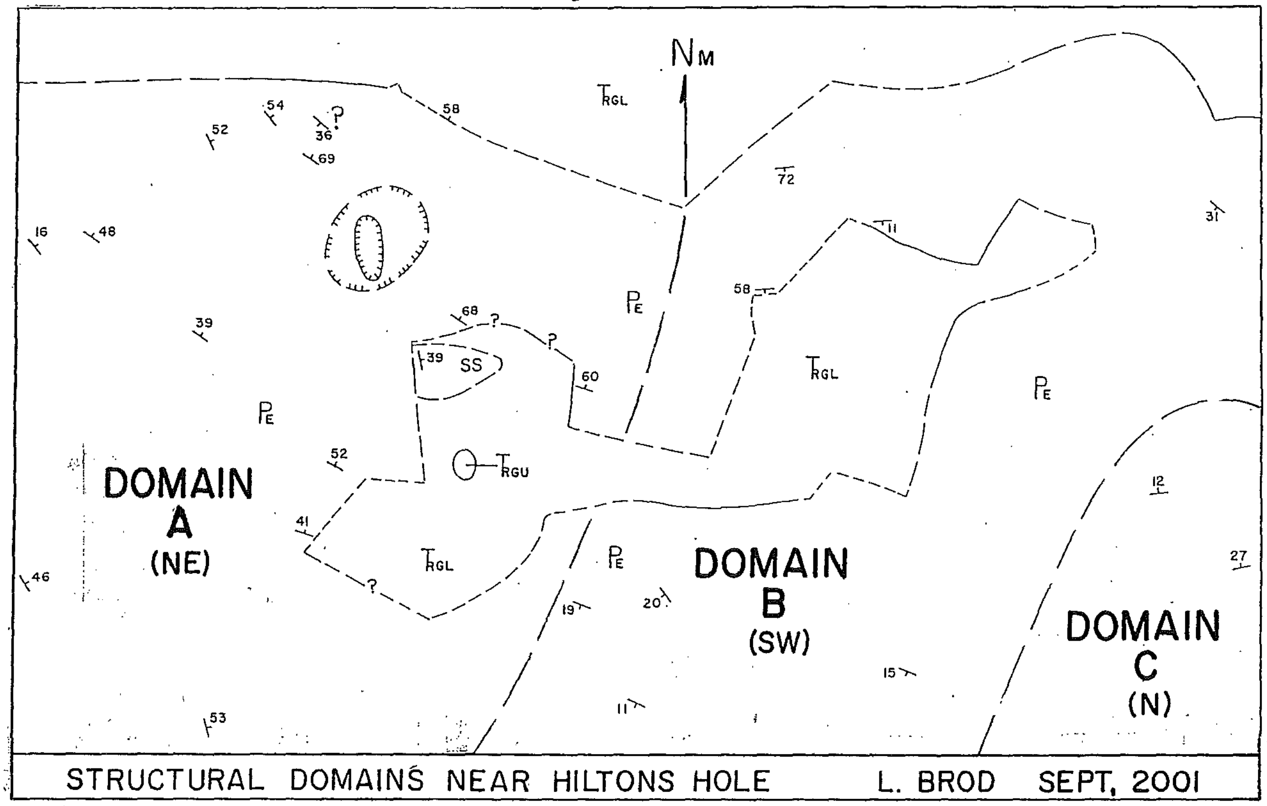
In order to understand the relationship of the siltstone lower member and the Epitaph, a topographic map with contour intervals of two feet was prepared and depicted an elevation differential of about 25 feet from a low elevation on the eastern end. (Fig. 9) The map also showed that the siltstone exposures were slightly depressed with respect to the slightly more resistant carbonate outcrops. Numerous strike and dip readings taken over the enlarged map area displayed a tendency to form groups of similar strikes and dips, which tended to differ markedly from those of adjacent areas. The groups are termed domains; three domains are shown in Fig. 10.

The anomalous and apparently chaotic structural relationships depicted in the enlarged map of Figure 10 appear to indicate some extensive tectonic deformation in this limited area. In addition to the lower member siltstone, there is what appears to be a small outcrop of the red upper member, about one meter in diameter. The presence of the small upper member outcrop and the larger outcrop of possible Scherrer sandstone may indicate extensive deformation in that small area.

Ground Water and Cave Development

The small cave indicates movement of ground water which caused solutional removal of the Epitaph. Inasmuch as the cave is bounded by insoluble siltstone beds, it is probable that the acidic water came from the subsurface, possibly through buried carbonate beds and moving southeast toward a lower elevation. Reaching the impediment of the apparently chaotic siltstone, the water may have risen to the surface, forming a spring resurgence.

During surveying, three small areas of massive crystalline calcite were found and noted on the map. The calcite is thought to have been deposited by hot water seeps at a resurgence which once existed here. The cave may have formed at a later time as the result of subsurface dissolution; its entrance formed as the result of surface erosion. At the present, rain water in the cave drains internally. Flow marks in floor sediment indicate water movement toward the west; the water appears to flow under a low ledge. There are no nearby resurgences where the cave water may rise.



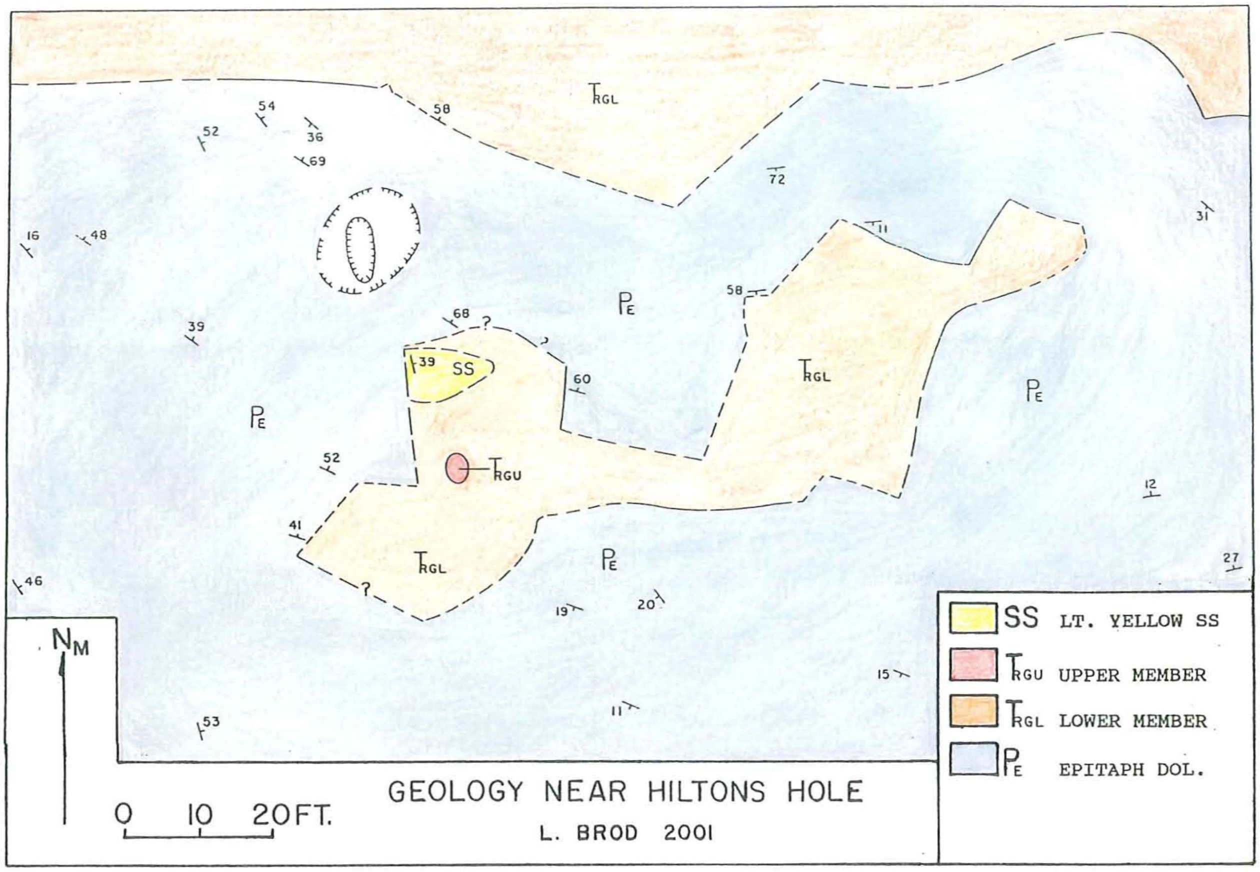
NM
DOMAIN A (NE)
DOMAIN B (SW)
DOMAIN C (N)
SS
STRUCTURAL DOMAINS NEAR HILTONS HOLE
L. BROD SEPT, 2001

FIGURE 10

Hypothetical Cross Section At The Cave

The position of the small cave near a major fault was both an interesting and fortuitous occurrence. For these reasons, a profile view was prepared extending through the cave in an approximately north-south direction, as shown in Fig. 11. As shown on the figure, the hypothetical profile was based on a number of constraints, including dip measurements and the probable thickness of Epitaph at this location. The profile was configured so that there was in the subsurface a continuous path for water flow to eventually emerge at the ground surface.

The resurgence of ground water at Hiltons Hole occurred at a time when the future path of Sawmill Creek was still buried under a thick blanket of sediment. Later erosion along Sawmill Creek provided a better alternative route for groundwater, so the cave drained and ceased to be a resurgence. This postulated history, of course, is highly speculative.



GEOLOGY OF ENLARGED AREA ON HILTON RIDGE FIGURE 8

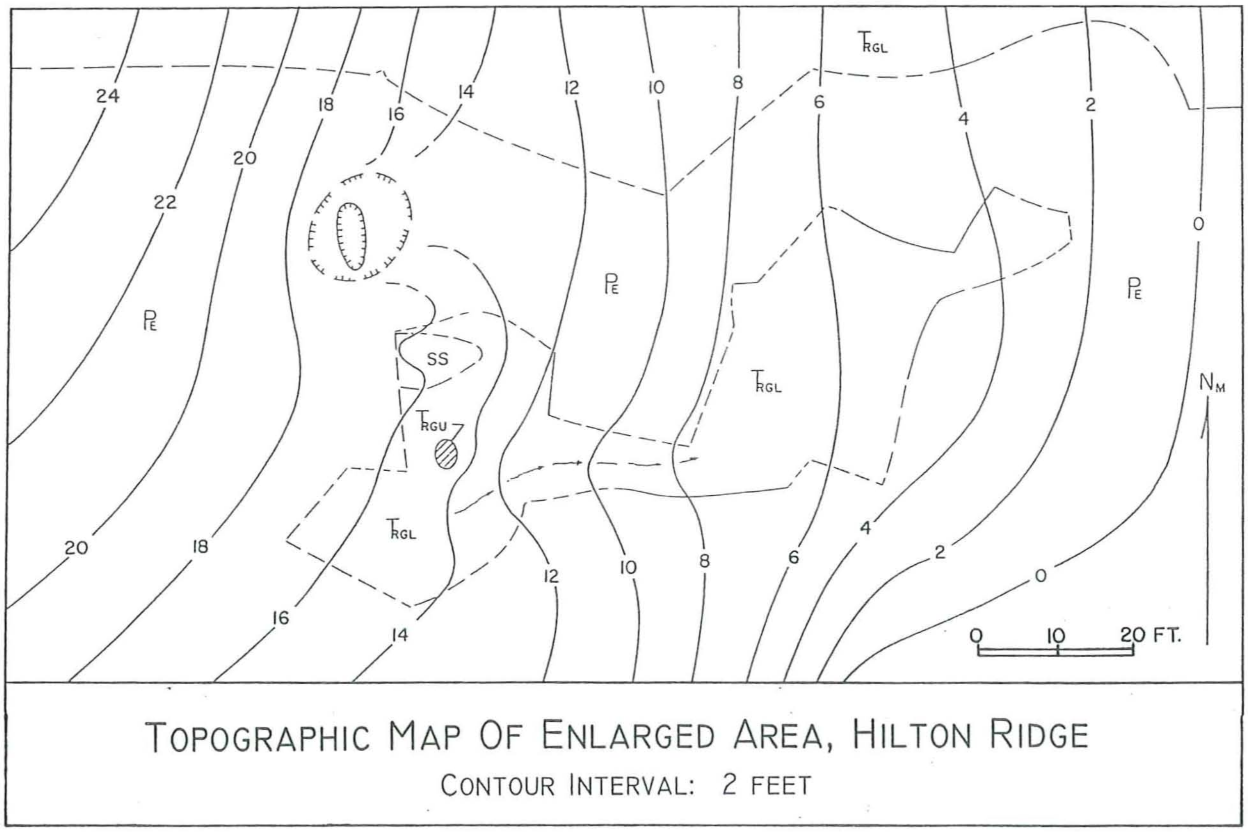


FIGURE 9

The Geology of Bells Ridge, at Cave of the Bells

Introduction.

Cave of the Bells is a large limestone cavern occurring in a relatively narrow band of limestone. The limestone is bounded on both sides by beds of insoluble siltstone and is also terminated on the southeast end by the same rock. The configuration of the cave and its hydrology is to a large extent controlled by the geology of the rock in which it has been formed. An attempt to understand the cave has provided an impetus to understand the geologic setting in which the cave formed.

The cave occurs in the northeast corner of the Mt. Wrightson 7.5 minute topographic quadrangle, in the northeastern corner of Santa Cruz County, Arizona. The geology in this region has been the subject of a paper by Harald Drewes, the USGS Professional Paper 748, published in 1972. Plate 3 of this paper covers the area in which the cave is located, at a scale of 1000 feet per inch. The primary objective of the paper has been the structural geology of this general area, but the paper also contains much information about the stratigraphy of the area.

The primary Feature of Plate 3 is the Sawmill Canyon Fault Zone, a narrow band of extensively faulted rocks. The fault zone is important because of the fact that the deformation has brought to the surface an extensive area of Paleozoic and early Mesozoic rocks which otherwise would lie buried beneath extensive Cretaceous rocks. Two additional areas are also included in PP748 and depicted on Plates 2 and 4; Plate 1 is a structural map on which the individual outcrops have been omitted, and where the structural relationships only are shown.

Cave of the Bells is reached by taking Forest Road 92 westward from Arizona Highway 93 to the vicinity of Onyx Cave, then turning off on Forest Road 4084 to a junction with Forest Road 4086. This latter road takes one a short distance to a parking area; a short walk up the valley brings one to the entrance of Cave Of The Bells.

The single Cave entrance opens near the northeastern corner of a limestone body about 175 metes wide. This limestone body trends northwest with a nominally constant width for about 200 meters; the northern margin merges with a similar limestone for a short distance (about 55 meters) while the south block continues.

The cave occupies the eastern end of the roughly rectangular limestone block. The cave entrance is near the bottom of a shallow valley, and the height of the hill increases over passages farther inside the cave. The cave is complex, with multiple levels forming a random pattern in places. Two passages descend to water; one on the eastern end of the cave descends steeply to a depth about 80 meters below the entrance. The cave contains deposits of fine red clay, resembling that found in many Missouri Caves and thought to be a deposit formed by extremely slow movement of water.

Stratigraphy Of Bells Ridge, At Cave Of The Bells

Bells Ridge is defined by several steeply dipping formations caused by faulting toward the eastern part of the Sawmill Canyon Fault Zone. The geology and structure of the local area is shown on Plate 3 of USGS Professional Paper 748 (Drewes, 1972). The area of interest is near the southeastern extremity of the fault zone, where Permian carbonate rocks are interleaved with Triassic siltstones.

Colina Limestone - The Colina is the lowest Permian rock exposed in the local area, It consists of a dark gray limestone containing some dark chert. Identification was made possible by the presence of fossils of the large spiral gastropod, genus Omphalotrochus. The Colina outcrops occur along the southwestern side of the carbonates on Bells Ridge. The southeastern margin of the Colina is poorly defined, but it may lie at a poorly exposed transverse fault.

Epitaph Formation - The Epitaph Formation is usually known as the Epitaph Dolomite. In this specific area however, the Formation is a mixed limestone and dolomite, so that in this report the author has termed it the Epitaph Formation. This formation is a light gray, medium bedded rock which occupies the larger area between two siltstone beds, as shown on the geologic map of the area (Figure 14). In this area the Epitaph contains clasts of light gray limestone in a matrix of gray rock. The color and texture of the clasts and matrix are similar, and the clast-matrix feature is not readily evident. In this respect, these outcrops differ from those exposed on Apache Ridge and in Lower Sawmill Canyon, where the clasts in the upper Epitaph beds are usually tinted red. Another component, a thin, yellowish-gray dolomite, was not observed here.

On Plate 3, Drewes shows three aspects of the Epitaph Dolomite: undifferentiated, an upper member, and a lower member. The upper member is specified as consisting of limestone and dolomite, while the lower member is specified as consisting of marlstone and dolomitic siltstone. In this author's limited reconnaissance, no outcrops resembling the lower member were observed. The area above the cave, defined by faults on Plate 3, was tentatively identified as the upper member.

Scherrer Formation - The Scherrer is not known to be exposed near Cave Of The Bells. A very small area, unidentified but color coded for Scherrer, was shown near the middle of the transverse fault on Plate 3. This area appears to be near the terminus of the Colina Limestone and was carefully searched, but no other outcrops were observed here.

Concha Limestone - The Concha is a cherty, fossiliferous limestone; in this area it outcrops only in a limited area near the edge of the Colina and was identified primarily because of the large amount of chert in the outcrops. No fossils were noted in the limited exposure here, perhaps because most of the outcrop consisted of chert which may have hidden fossils.

Gardner Canyon Formation, lower member - The lower member of the Gardner Canyon Formation is a tan siltstone, often having a light reddish tint. Farther east, in the Lower Sawmill Canyon and on Apache Ridge, the siltstone is almost universally tan. Steeply dipping beds of the siltstone are interleaved with the carbonate beds. The siltstone is less resistant to weathering than the carbonates; as a result, streams and valleys tend to occupy the siltstone outcrops. The lower member contains a limestone marker bed (Drewes' marker bed A), a short section of which occurs at the edge of the parking area southeast of the cave entrance. The limestone bed is only about one meter thick in that place.

Gardner Canyon Formation, upper member - The upper member of this formation is generally a brick red siltstone. The red siltstone is found at only two places on this author's map, one in a small area at the bottom of the small streambed between the cave entrance and the parking area, and the second in a small ravine at the southwest extremity of the map where several faults converge (Shown on Plate 3). Farther south, the slope of the ridge diminishes and the flat part of the valley, not shown on this author's map, is formed in the red siltstone of the Gardner Canyon upper member. The occurrence higher on the hill probably results from the presence of a fault shown in this area on Plate 3.

In addition to the common red siltstone, the upper member also exhibits outcrops of gray and gray-green siltstone. A number of small outcrops with these less common colorations occur on the hillside above the parking area. No additional formations or members occur in the designated map area.

Younger Surfaces - No younger features occur in this vicinity, with the possible exception of alluvial deposits in the shallow valley south of the surveyed area.

Mineralization

A mine shaft is shown on the Mt. Wrightson 7.5 minute map immediately north of Cave Of The Bells. People who have visited the mine site report that there is a nearby talus pile, indicating some digging has occurred there. The Snyder Mine, shown with three adits, occurs on the opposite side of a small hill about 0.3 mile away, to the northeast. Both mines are apparently abandoned.

A study of the mineralization in Cave Of The Bells was made by Kendrick L. Day, and the results were published in a newsletter of the Escabrosa Grotto, Vol.6, no. 1, March 1976. Escabrosa Grotto is a chapter of the National Speleological Society and meets in Tucson. Mr. Day utilized X-ray diffraction to identify the presence of calcite, aragonite, gypsum, hydromagnesite, amorphous silica, and huntite. Two of these minerals contain magnesium, indicating the proximity of magnesium-bearing rocks, such as dolomite. The source of the magnesium is probably the Epitaph beds now exposed on the surface.

Structure of Bells Ridge

Bells Ridge is a low linear ridge extending west-northwest, one of several generally parallel ridges formed by faulting. The ridge is a westward extension of Hilton Ridge, a short distance east-southeast of Bells Ridge. The ridge name is an informal name derived from the Cave Of The Bells, which opens on its northern side. The structure and stratigraphy of Bells Ridge is shown on Plate 3 of USGS Professional Paper 748 (Drewes, 1972).

The primary outcrop on Bells Ridge is the Epitaph Formation of Permian age. Southwest of the cave entrance is a linear outcrop of the underlying Colina Limestone. The linear bands of Epitaph and Colina are the result of steeply dipping beds in both formations. The two carbonates are bounded by similarly linear beds of the Gardner Canyon Formation lower member, a tan-colored siltstone. The cave entrance is formed upon a fault between the Epitaph Formation on the south and the lower member on the north; the fault trace is easily observed at the cave entrance. The fault can be readily traced on the surface for 165 meters to a place where two faults converge and the contrasting siltstone is terminated.

Drewes shows the entrance fault continuing in the Epitaph beds, curving somewhat to the south and eventually reaching a window of Concha Limestone. Surface surveys by this author found the Concha outcrops, distinguished by large masses of chert, but the fault as mapped by Drewes could not be followed over the crest of the hill where the surface outcrops were minimal.

The Epitaph and Colina beds are bounded on the south east, and north by beds of the Gardner Canyon lower member, On the eastern end, faulted siltstone beds define an eastern boundary to the carbonates, forming an insoluble barrier on the surface, between the siltstones on the north and the south.

On Plate 3, Drewes shows an essentially linear siltstone band of uniform width which forms the northern boundary of the Epitaph outcrops forming the ridge. Mapping by this author, as noted, showed that the faulted boundaries of the siltstone converged, and that the limestone band was missing for a short distance. At this point, the Epitaph of The ridge joined the Epitaph on what had been the far side of the siltstone. Some distance farther west, the siltstone bed again reappeared and resumed its previous alignment.

Drewes shows a short anticlinal fold in the vicinity of the Concha outcrop. A few steep dips have been noted in this area, but a fold was not observed by this author.

The contact between the siltstone and the carbonate rocks is often rather irregular, apparently consisting of a series of small faults with limited length which intersect each other at odd angles. One reentrant of the siltstone into the Epitaph occurs on the southeast end of the area; several inliers and small windows occur on the southwestern margin of the limestone.

One window of lower member siltstone occurs on the fault passing through the cave entrance. This window is completely enclosed by the Epitaph Formation. Near the southeast corner, two windows bounded by small faults are surrounded by siltstone, one of Epitaph and the second of Colina. An apparent second small Colina window occurs farther northwest along the larger body of Colina.

Strike and dip readings taken over much of the mapped area shows a number of high dip angles. Such high dips probably should be expected in this type of setting.

Two small windows of the Epitaph are shown on Drewes' Plate 3, near the southeast corner of the Cave Of The Bells block. One of these small window was surveyed by this author. A fault was noted near the southeast end of this window.

Hydrology

As noted previously, two relatively small pools of water are found at appreciable depth in the cave. The surface of the eastern pool, at the time of survey, occurred at a depth of about 270 feet (82) meters. A careful examination of the Mt. Wrightson topographic map showed that surface features did not reach a sufficiently low altitude until the confluence of Cave Creek and Sawmill Creek was reached. A search of Cave Creek revealed two small resurgences a short distance downstream from the confluence, as shown on the geological map of the resurgences in this report.

The geology of the resurgence area was mapped, showing that the water rose through a thin limestone bed, a marker bed in the Gardner Canyon lower member. This position of this marker bed was, over a short distance, as low as it could possibly be. Only a few meters to the east, the marker bed was displaced about 75 meters to the north where it was too high to serve as a resurgence.

There are two and sometimes more places where the water flows out to the surface. The primary resurgence occurs at the base of a low ledge composed of or covered by soil. The water emerges onto a wide but low platform, also composed of soil, only about 6 to 8 inches above the normal level of the creek. This resurgence is generally exposed except during minor floods. The second resurgence occurs about 27 meters upstream; the stream flows out at stream level and it is generally difficult to monitor except during dry weather. A third, tiny resurgence, occurs on top of a limestone boulder and is essentially a wet-weather seep.

The southern resurgence, in Gardner Canyon, generally fails to flow during a lengthy spell of dry weather. The resurgence in Cave Canyon, however, has continued to flow over a period of several years during which the flow was monitored, at least at monthly intervals. That flow must be derived from somewhat more extensive sources. It is believed that the flow comes partially from Cave Of The Bells, from other smaller caves, and from beneath the bed of Sawmill Canyon.

Geology Of Onyx Hill

Introduction

Onyx Hill is a marrow ridge, the southeastern end of a longer ridge in northeastern Santa Crux County, Arizona. The hill (ridge) is terminated on its southeast end by erosion. On its northwest end, the hill (as defined herein) is separated from the northwest extension of the ridge by a saddle. Onyx Hill is noted primarily for the presence of Onyx Cave, a cavern about 2 km in length, which was once mined for its cave onyx about at the beginning of the previous century.

The central core of Onyx Hill, in which the cave is formed, is composed of a lower Permian limestone, termed the Rainvalley Formation. The limestone is somewhat more resistant to erosion than the surrounding outcrops, thus producing the ridge in which the cave was later formed. In addition to minimal mining of the cave onyx from parts of the cave near the entrance. a number of surface sites were mined. During this author's geologic surface surveys, three mines of varying size were found, all on the northeast side of the hill near the contact of the limestone with insoluble rock. One such site was opened into the hillside as a small room. The discarded overburden and much massive crystalline calcite was found in a large talus platform outside the mined room.

The geology of the area was first mapped in detail by Harald Drewes of the United States Geological Survey. Three geology maps and a structure map were published in Professional Paper 748 in 1972, with the emphasis on the structural geology of the area. One of the three maps, Plate 3, was devoted to the structure and the geology of the Sawmill Canyon Fault Zone, a southeastward oriented band of faults extending from the Santa Rita Mountains to the edge of outcrops on the eastward side of the range.

This author undertook a more detailed geologic mapping effort in conjunction with a study of the geology, morphology, and hydrology of the cave. The surface geology was surveyed beginning in November 2001 and continuing until February 2003. During the latter part of 2002, the surface morphology along Cave Creek was also studied, with a number of terraces along Cave Creek surveyed.

The surface geology of Onyx Hill was mapped along the contact of the central limestone, including narrow peripheral areas. The southwest part of the hill was difficult because of steep slopes caused by the proximity of Cave Creek. The northeast side of the hill was surveyed in more detail. Surveying continued from the southeast terminus of the hill to a saddle on the northwest where the central limestone outcrop was terminated by quartzite.

The northeast side of Onyx Hill was bordered by Forest Road 4084. An igneous dike crossing over Onyx Hill extended to the road, where it was offset to the northwest. Detailed surveys of the dike revealed appreciable dimensional errors on Plate 3 of PP748.

Stratigraphy Of Onyx Hill

Detailed surveys of Onyx Hill by this author showed general correspondence between those surveys and those published on Plate 3 of Professional Paper 748, with the principal differences being the result of the differences in scale, in most places.

Paleozoic Era - Colina Limestone

The Colina Limestone is a dark gray to black limestone with minor amounts of black chert. In addition, fossils of the large gastropod of the genus Omphalotrochus occur at various places within the rock. Drewes' Plate 3 shows a very small outcrop area of Colina Limestone toward the northwest, a short distance beyond the bounds of the central limestone unit and beyond the limits of the author's mapped area. However, a small outcrop of Colina Limestone was found at the southeast end of Onyx Hill. There, a small block of Colina Limestone containing an Omphalotrochus fossil had become dislodged from the hillside and rolled down onto a low terrace along Cave Creek. No other outcrops of Colina were found, though Colina rocks may occur in the subsurface.

Epitaph Formation

The Epitaph Formation in this general area is mixed limestone and dolomite. Drewes found no trace of the formation on Onyx Hill, but some rock in the southeastern part of the hill exhibited light red inclusions similar to the upper, red tinted Epitaph beds found on Apache Ridge and Lower Sawmill Canyon to the north. At the present time, this problem has not been resolved.

Scherrer Formation

The Scherrer Formation is a mixed limestone and dolomite, with a basal siltstone member. Onyx Hill exhibits a good display of three members which have been observed in this general area. A quartzite/sandstone bed adjacent to the central limestone probably is the upper quartzite member. A dolomite bed southwest of the upper quartzite bed is thought to be the middle dolomite member. Because of a cliff near the base of the hill, a traverse from the upper part of the hill was not attempted, but a thick quartzite (generally white in color) observed at creek level appears to be the basal quartzite member shown on Drewes' stratigraphic column. The basal siltstone member was not observed here.

A small outcrop of light colored sandstone is found on a low terrace on Cave Creek, probably a minor remnant of the Scherrer.

Concha Limestone

The Concha Limestone is a very fossiliferous, very cherty formation of lower Permian age, younger than the Scherrer Formation. It is not known to occur anywhere near Onyx Hill.

Rainvalley Formation

The Rainvalley Formation is primarily a limestone, which forms the central region of Onyx Hill. In addition, a more dolomitic set of beds to the northeast, in conjunction with sparse beds of sandstone and siltstone, are reported by Drewes on Plate 3.

Two additional exposures to the southeast form a generally linear set of limestone hills. These three hills and a smaller exposure of the limestone northwest of Onyx Hill constitute the total exposure of the Rainvalley in and near Onyx Hill. Also, a tentative exposure of the Rainvalley Formation has been shown on Plate 3 north of the Apache Ridge, but its presence there has not been verified in the present study.

The third Rainvalley exposure occurs almost a mile southeast of Onyx hill, where the formation intersects Gardner Canyon. Here, the limestone beds are somewhat shaly and include beds of mudstone. The mudstone beds are unconsolidated, resembling silty yellow soil, and are easily eroded. The Rainvalley exposures there appear to be broken up to a large extent and mixed with outcrops of the Gardner Canyon upper member siltstone.

Additional Rainvalley outcrops are shown northwest of the main Rainvalley body containing the cave. This smaller outcrop was not examined during this survey. A small outcrop, apparently designated as Colina by a small identifier, occurred only 60 meters beyond the surveyed body of Rainvalley; a brief examination revealed that it probably a Colina outcrop, but no careful study was made.

Profile B-B′ on Plate 3 shows that the Rainvalley beds on Onyx Hill are almost vertical and sloping steeply northeast. Also, the dolomitic marker horizon is defined by an almost straight line (d) about at the middle of the Rainvalley outcrop area. Inasmuch as the horizon d is specified as the base of a more dolomitic sequence, higher beds in this sequence would occur in the northeastern part of the Rainvalley outcrop band. No effort was made to determine the approximate border of the dolomitic sequence.

The Rainvalley Formation contains some fossils but they are generally sparse and in poor condition. Some apparent fossils are of questionable origin and unidentifiable. Identifiable fossils are found inside the cave but their stratigraphic position is unknown. Numerous fossils occur in the cave 85 meters from the entrance, in what is called The Garbage Pit, a short lower section under a descent of about 10 meters.

Some horizons contain profuse chert. Outside, along the cave trail, are rust colored nodules of what appears to be chert. Broken surfaces of some nodules show that they contain sand in addition to chert.

Mesozoic Era - Triassic System

Gardner Canyon Formation, Lower Member

The lower member of the Gardner Canyon Formation is commonly a tan colored siltstone containing beds of white limestone. On Onyx Hill, however, the tan siltstone was not observed. Drewes shows a relatively narrow band of the lower member between the northeastern Rainvalley margin and the upper member. This band continues along the Rainvalley outcrop from its eastern end northwest to a mapped fault, which cuts across the Rainvalley beds. Within the noted area primary outcrops consist of red siltstone and some red sandstone, unlike typical lower member outcrops. These will be tentatively considered to be the lower member.

The area within this band contains four narrow beds of white or nominally light colored limestone, reminiscent of the lower member marker beds. These beds, however, become sparse and vanish before reaching the fault. Based entirely on the presence of the marker beds, the narrow band thus defined appears to be the lower member of the Gardner Canyon Formation, as shown by Drewes.

The upper member of the Gardner Canyon Formation consists of a brick-red siltstone. It extends along the entire northeastern margin on the northwest, and along the probable lower member on the southeast, On the northwestern end, the Rainvalley Limestone is in contact with what appears to be the upper member of the Scherrer Quartzite. The Rainvalley-Scherrer contact continues up the hill southwestward to the crest of the ridge and down the steeper southwest side. This contact continues down the southwest side of Onyx Hill, eventually enclosing the main Rainvalley limestone body.

Tertiary System

Igneous Dike, of Uncertain Age

A narrow igneous dike of Tertiary age has been depicted on Plate 3, extending from a larger batholith south of Cave Creek, across Onyx Hill and terminating north of Sawmill Creek, with some gaps.The dike is fairly well defined north of Onyx Hill, but its trace over the crest of Onyx Hill is not shown. The batholith and dike are composed of rhyolite porphyry, according to Drewes.

A dike segment has been surveyed by this author south of Onyx Hill, extending northeast. If this orientation were maintained, it would intersect the cave about 30 meters northwest of the entrance. However, no such intersection has been observed within the cave. Followed southwest on the northeast side of the ridge, the dike ascends the hill and would intersect the hilltop southeast of the cave. Unfortunately, outcrops of the dike are sparse near the hill crest. On the basis of very sparse dike fragments, it appears that the dike crossed Onyx Hill southeast of the present cave entrance. It was subsequently displaced northwest on the south side of the present cave, thereby missing the present cave entirely.

Adjacent Igneous Deposition

Although not directly associated with Onyx Hill, the dike extends northeast into a region of igneous rock which may have had some effect upon the general geology of the area. The region of interest lies between northeastern Onyx Hill and southwestern Lower Sawmill Canyon. Specifically, the area lies northeast of the Forest Road, FR-4084 and the south side of Sawmill Creek.

There are two components listed by Drewes on Plate 3, both of which are considered to be members of the Gardner Canyon Formation, most likely because they are interbedded with conglomerate of that formation. The first component, age dated at 192 Ma, is listed as dacite flows, intrusives, and tuff. The second component is listed as a volcanic breccia in a mudstone matrix, apparently fluvial.

Some reconnaissance mapping was conducted by this author in order to understand the relationship of these components to the Onyx Hill and the Lower Sawmill Canyon areas. One finding: the igneous dike cut the older volcanics and thus was younger. One additional observation was that the highest part of the ridge between FR-4084 and Sawmill Creek appeared to be a deposit of almost pure quartz. The quartz outcrop appeared to be roughly about thirty feet (roughly 10 meters) in diameter.

Tertiary Gravels

Onyx Hill is relatively high; the crest stands about 75 meters above its base. However, there is no trace of the coarse Tertiary gravel found on other high hills in the vicinity. On profile B-B' of Plate 3, Drewes shows the Pliocene Pediment intersecting Onyx Hill below the crest of the hill. If this is the case, residual gravel would have been eroded from the steeper hillsides. Remnants of the coarse gravel, primarily sandstone, occur near the base of Onyx Hill in Pleistocene terraces and along Cave Creek downstream from the cave. The coarse gravel is generally covered by finer sediments one to two meters thick.

Pleistocene and Holocene Sediments

Younger deposits consist primarily of fluvial deposits laid down by streams. Eolian deposits may be present in small amounts but have not been identified.

Mining

Mention has been made previously of the limited mining of cave onyx at Onyx Hill. The only other known trace of mining occurs in the form of a small test pit in the northernmost limestone marker bed near the base of the hill. There is no sign of mineralization. Two old concrete platforms occur a short distance north of FR-4084 and an old, circular concrete tank occurs south of the road at the same locality. These remains may have been associated with mining of some sort, possibly the onyx mining on Onyx Hill.

Structure Of Onyx Hill

The structure of Onyx Hill is fairly simple. On section B-B' of Plate 3, Drewes has depicted a cross section passing through Onyx Cave, showing the beds there sloping steeply toward the northeast. Several faults are shown essentially parallel to the bedding planes.

The Permian and Triassic rocks associated with Onyx Hill constitute the southern side of the Sawmill Canyon Fault Zone. The Fault Zone is an intensely faulted area, spreading from a vertex on the northwest to a wider area on the southeast, where the Paleozoic and Mesozoic rocks are buried beneath Cenozoic Gravel.

Across the Fault Zone, from southwest to Northeast, are three bands of Paleozoic rocks, separated by bands of Triassic rocks. The first band, to the southwest, is the Onyx Hill geologic area. The second band contains the Lower Sawmill Canyon, Hilton Ridge, and Cave Of The Bells geologic areas. The third band, to the northeast, contains the Apache Ridge geologic area. These three areas contain features of speleological or hydrological interest. The presence of these features is thought to be highly dependent upon the geologic structure.

The fault on the southwest side of the Onyx Hill Paleozoic beds separates the Paleozoic rocks from extensive Cretaceous outcrops on the southwest side of the Sawmill Canyon Fault Zone. In addition, the batholith feeding the igneous dike crossing Onyx Hill occurs among the Cretaceous outcrops.

Smaller faults occur along the edges of the primary limestone outcrop, generally extending along or across the limestone contact. All appear to be fairly short and do not appear to extend for more than about 30 meters. Two apparently short faults cut completely across the limestone at and near its northwestern end. Three (or perhaps more) small faults occur along the contact between the limestone and the Scherrer upper member toward the western margin. Several short faults apparently occur in the vicinity of the cave entrance. One relatively short fault offsets a limestone marker bed near the southeastern end of Onyx Hill.

The Tertiary dike extends down Onyx Hill in a relatively straight direction. However near Forest Road 4084, the dike turns abruptly northwest and continues in that direction for over 100 meters, crossing the road at a low angle. The dike then turns to a general north-northeast direction and continues in that direction. The dike is believed to follow fault fractures.

The thin limestone marker beds which are components of the Gardner Canyon lower member extend northwest from the southeastern base of Onyx Hill. The beds continue northwest for at least half the length of Onyx Hill. The beds apparently terminate just prior to a fault, leaving what appears to be a blank space. The blank area may indicate a structurally disturbed area.

Surficial Deposits

A number of surficial deposits of possibly hydrothermal origin occur on Onyx Hill. Of special interest are the massive calcite deposits which apparently were dug during mining activity. Some limited mining of cave onyx (calcium carbonate wall and floor deposits) occurred, apparently around the beginning of the 20th. century. The cave onyx was used for building facings, but the onyx was sensitive to acidic rain and the market for this material was short lived.

At least three small onyx mines occur on the northeast side of Onyx Hill, a short distance above the contact of the limestone with the underlying siltstone. The largest mine occurs about 100 meters northwest of the igneous dike. There, large blocks of crystalline calcite have been stacked outside the mine face to form a level platform. Two smaller mine features occur farther northwest near the contact, the second only a short distance above a short fault.

Other unmined calcite sites occur along the hillside near the contact. In places, the calcite appears to occur where the calcite-bearing water seeped out along a bedding plane or fault fracture. All known exposures of calcite occur on the northeast side of Onyx Hill, which exposes the upper side of the steeply sloping beds.

In one such place, a peculiar appearing rock was found and later examined. The rock at first view exhibited what appeared to be numerous small pores, similar to a piece of bone. However, under more careful examination the rock was seen to contain numerous and closely spaced, small pyramidal depressions. The rock appeared to be a cast of a group of very small crystals, about 3 to 4 mm in length and 1 mm or less diameter. Planar crystal facets occurred on the interior surfaces. The matrix material was tested and found to be quartz, Apparently the quartz overcoated the crystals, which were later dissolved.

Other mineralization occurs near the crest of the ridge, along the footpath leading to the cave entrance. This mineralization it in the form of thin coatings, some of contrasting colors, appearing to be concretionary over an uneven substrate. The coatings apparently were deposited by water.

Terraces In The Vicinity Of Onyx Hill

Cave Creek borders Onyx Hill on the southwest side, with a widening terrace in the upstream direction, which narrows and disappears as Cave Creek reaches the bottom of Onyx Hill. There, Cave Creek turns to the northeast and the terrace then again appears on both sides of Cave Creek. The terrace continues along Cave Creek and continues on one or both sides of the creek for a considerable distance. The age of this terrace is unknown to this author, but it is probably late Pleistocene.

In places where road cuts and stream erosion has cut into the terrace,it can be seen that the terrace is depositional, with about a meter of finer sand and silt overlying an underbed of coarser cobbles and small boulders probably derived from the coalesced alluvial fans bordering the eastern flank of the Santa Rita Mountains. The coalesced alluvial fans were deposited in late Tertiary time and began to be eroded at about the beginning of Pleistocene time.

This widespread terrace along much of Cave Creek is the oldest of a sequence of terraces, with three younger terraces being more limited in extent. The oldest, highest terrace is termed Qt4, as shown in Figure 12. One small, slightly lower terrace remnant is termed Qt3. A lower and somewhat more extensive terrace occurs primarily along Cave Creek, downstream from the small side canyon entering from the south. This third terrace, Qt2, extends eastward immediately adjacent to Cave Creek and continues northeastward past the Forest Service Road, FR-4085. A smaller segment of this terrace about 80 meters long occurs on the south side of cave creek. An even smaller remnant occurs where the smaller side canyon joins Cave Creek. The fourth terrace, Qt1, occurs on the south side of Cave Creek from the small side canyon eastward past FR-4085 and westward on the north side of Cave Creek for about 140 meters.

The northern occurrence of Qt1 begins at an isolated exposure of a light gray quartzite, possibly the Permian Scherrer formation, where the Qt2 narrows and descends about one meter to the level of Qt1. It appears that the quartzite pedestal shifted the flow of the creek toward the south, thus preserving remnants of the higher terrace along Cave Creek.

A remnant of the higher terrace, Qt4, occurs upstream, a short distance prior to where the lowest terrace terminates. This terrace remnant extends only a short distance upstream (beyond the limit of the map). It terminates where the steep, stream-cut bank meets the basal slope of Onyx Hill. At this remnant of terrace Qt4, Cave Creek is rather narrow, confined between a cliff of conglomerate on the south and the steep bank below the edge of the terrace.

Farther upstream, the canyon widens somewhat. About 150 meters upstream, a cliff of white quartzite occurs above a lower bed of conglomerate. Somewhat farther upstream, another terrace occurs, probably a larger remnant of the higher terrace, Qt4.

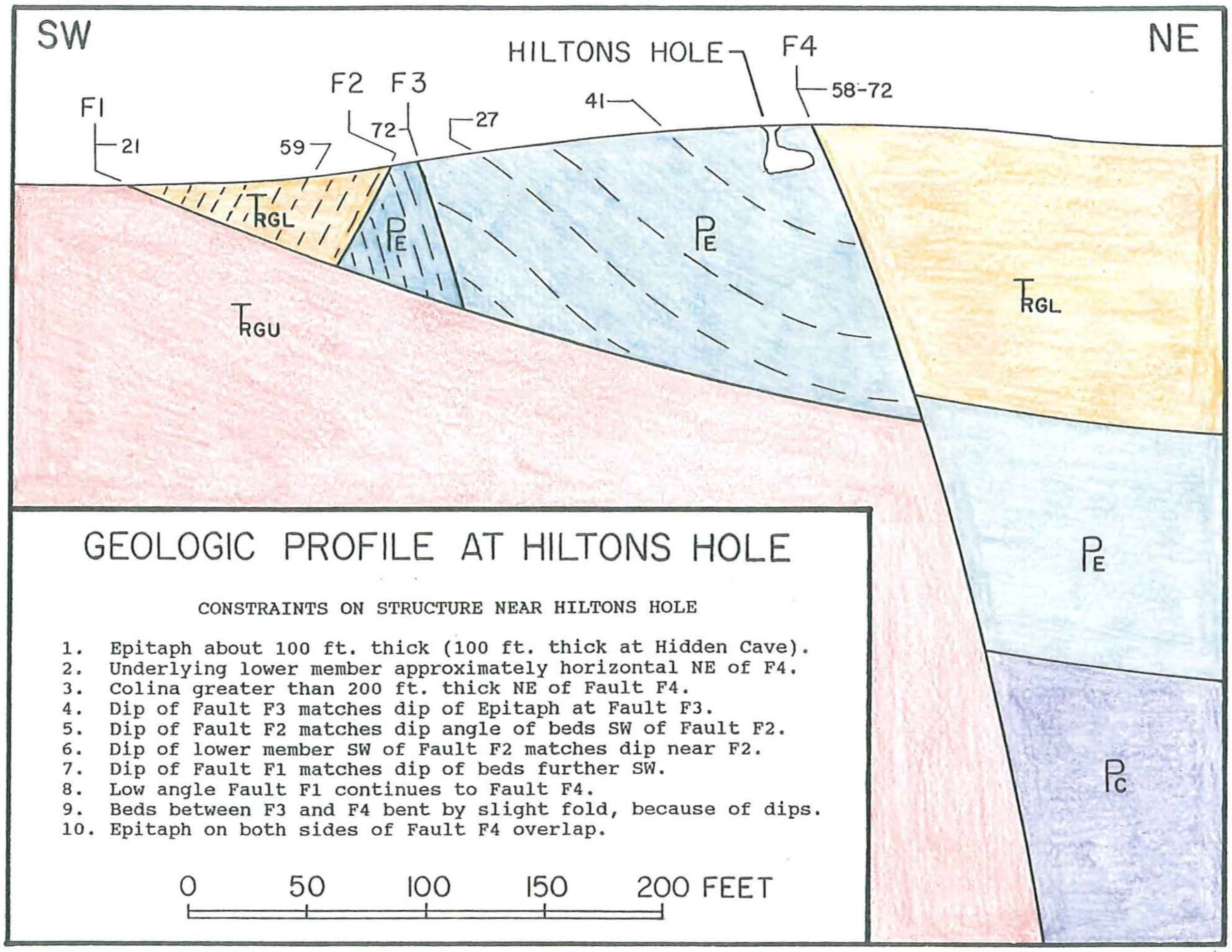
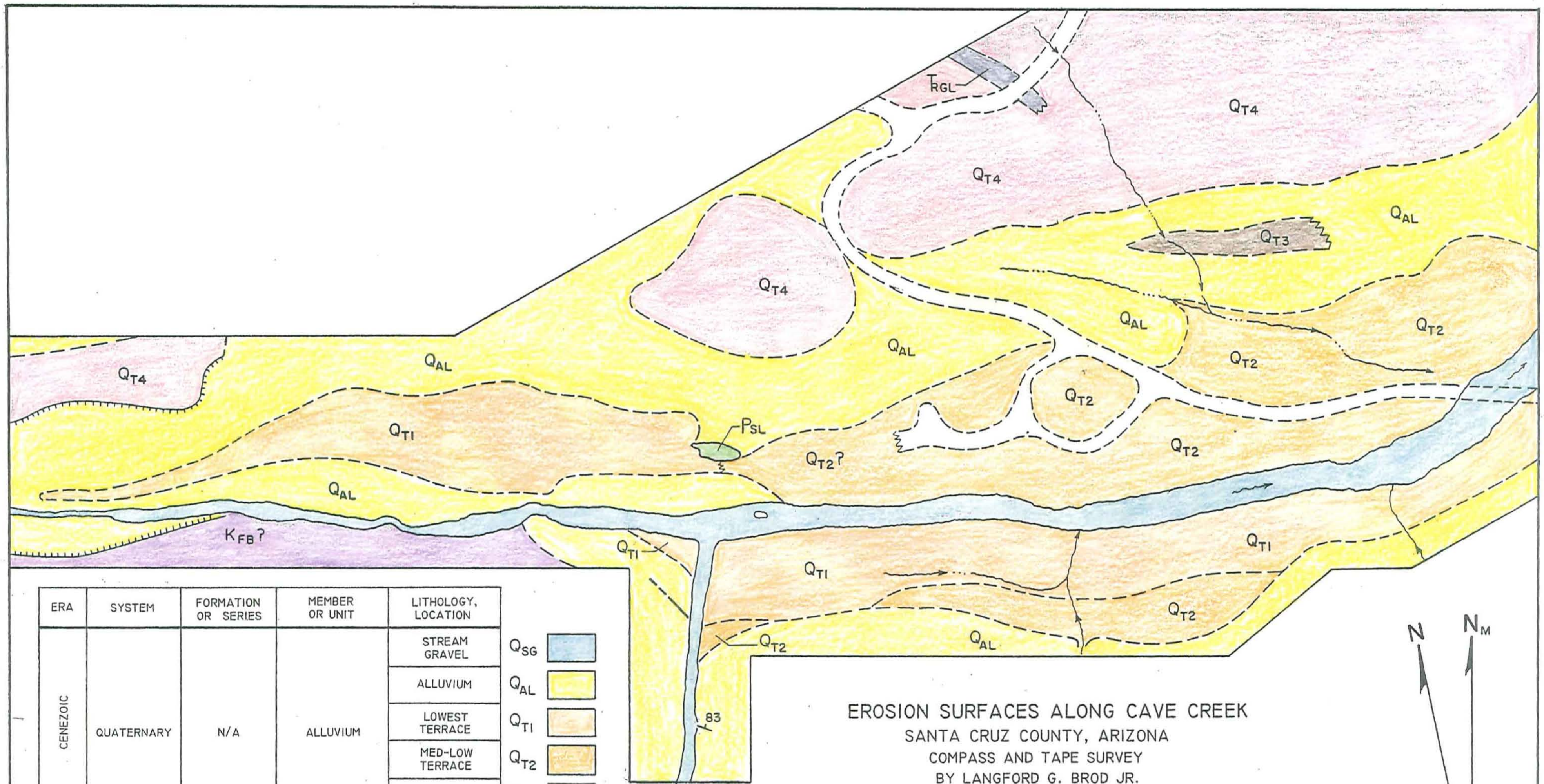

SW
NE
HILTONS HOLE
F1
F2
F3
F4
21
59
72
27
41
58-72
TRGL
PE
TRGU
PC
GEOLOGIC PROFILE AT HILTONS HOLE
CONSTRAINTS ON STRUCTURE NEAR HILTONS HOLE
1. Epitaph about 100 ft. thick (100 ft. thick at Hidden Cave).
2. Underlying lower member approximately horizontal NE of F4.
3. Colina greater than 200 ft. thick NE of Fault F4.
4. Dip of Fault F3 matches dip of Epitaph at Fault F3.
5. Dip of Fault F2 matches dip angle of beds SW of Fault F2.
6. Dip of lower member SW of Fault F2 matches dip near F2.
7. Dip of Fault F1 matches dip of beds further SW.
8. Low angle Fault F1 continues to Fault F4.
9. Beds between F3 and F4 bent by slight fold, because of dips.
10. Epitaph on both sides of Fault F4 overlap.
0
50
100
150
200 FEET

FIGURE 11



ERA	SYSTEM	FORMATION OR SERIES	MEMBER OR UNIT	LITHOLOGY, LOCATION	
CENEZOIC	QUATERNARY	N/A	ALLUVIUM	STREAM GRAVEL	Q_{SG}
				ALLUVIUM	Q_{AL}
				LOWEST TERRACE	Q_{T1}
				MED-LOW TERRACE	Q_{T2}
				MED-HIGH TERRACE	Q_{T3}
				HIGH TERRACE	Q_{T4}
MESO-ZOIC	CRETACEOUS	FORT CRITTENDEN	BROWN CONGLOMERATE	COMGLOMERATE, LITHARENITE	K_{FB}
	TRIASSIC	GARDNER CANYON	LOWER MEMBER ?	WHITE LIMESTONE	T_{RGL}
PALEO ZOIC	PERMIAN	SCHERRER	LOWER QUARTZITE	LIGHT GRAY QUARTZITE	P_{SL}

EROSION SURFACES ALONG CAVE CREEK
SANTA CRUZ COUNTY, ARIZONA
COMPASS AND TAPE SURVEY
BY LANGFORD G. BROD JR.
2002

FIGURE 12

Hydrology

Ground water enters Onyx Cave through cracks and fissures in the overlying limestone, forming drips and small pools. The water ultimately drains from the cave. Cave passages containing muddy sediments occur in the northwestern part of the cave, in passages aligned approximately along the strike of the steeply dipping beds. At the present time incomplete surveys have traced these apparent drains southeastward along the northeast side of the hill. The passages have descended about 50 meters below the nominal upper level of the cave and are continuing downward. The end of surveyed passage is about 20 meters above the base of Onyx Hill.

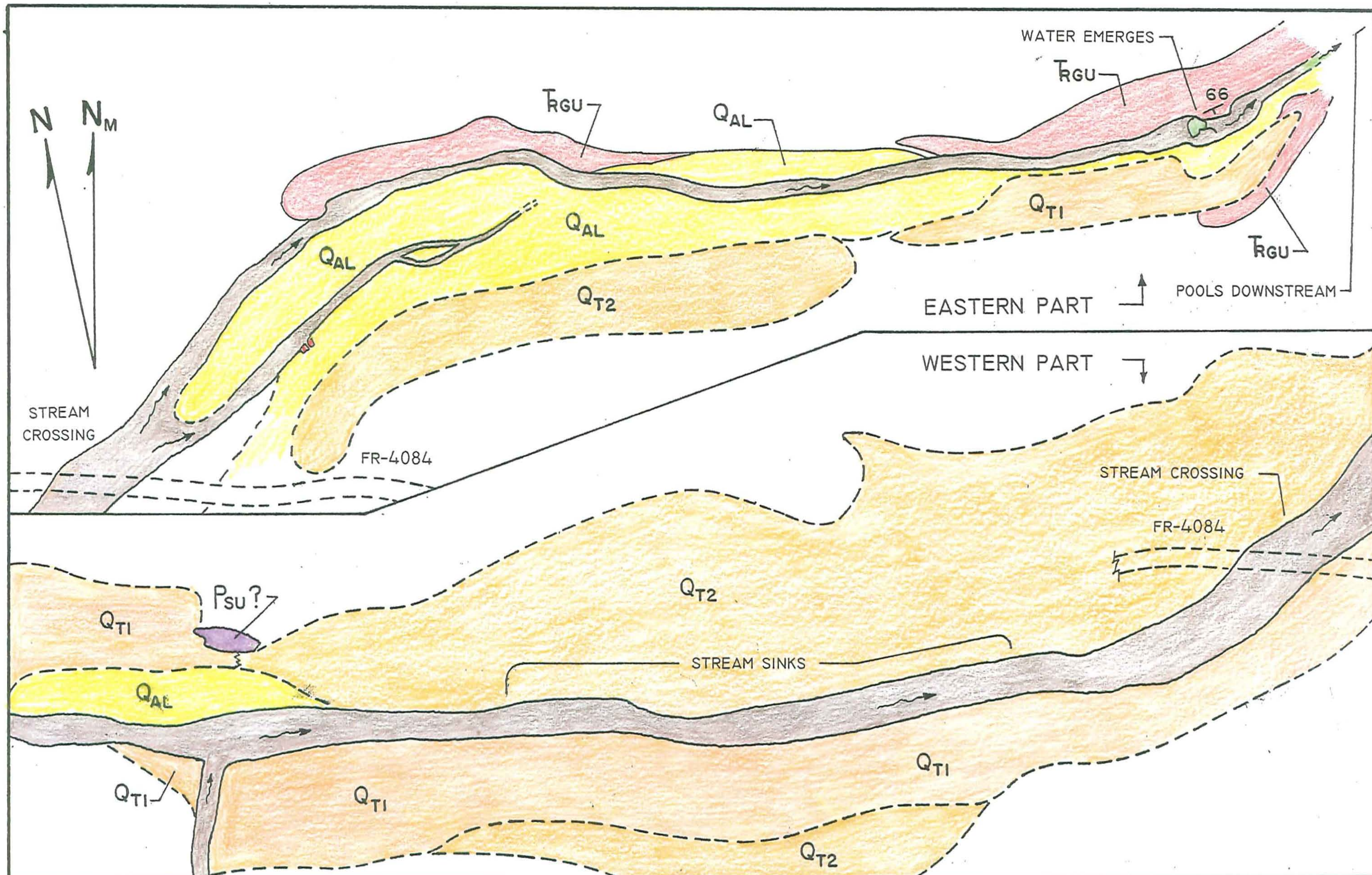
The first likely site of a resurgence occurs where Forest Road 4084 crosses Cave Creek. This place is just beyond the base of Onyx Hill. The Rainvalley bed should cross here but the site is covered by alluvium. Furthermore, the tentative presence of faults shown on Plate 3 may offset soluble limestone in the subsurface.

In order to monitor the presence of any water rising into the gravel, careful examinations of the stream was carried out on a number of occasions. It was found that the gravel bed terminated about 280 meters upstream from the road crossing and about 170 meters downstream, where the stream when flowing emerged onto the insoluble red siltstone of the Gardner Canyon upper member, shown on Figure 13. When the flow of water ceased at the downstream gravel terminus, it also ceased at the upstream end, thus implying no additional efflux of water from the cave.

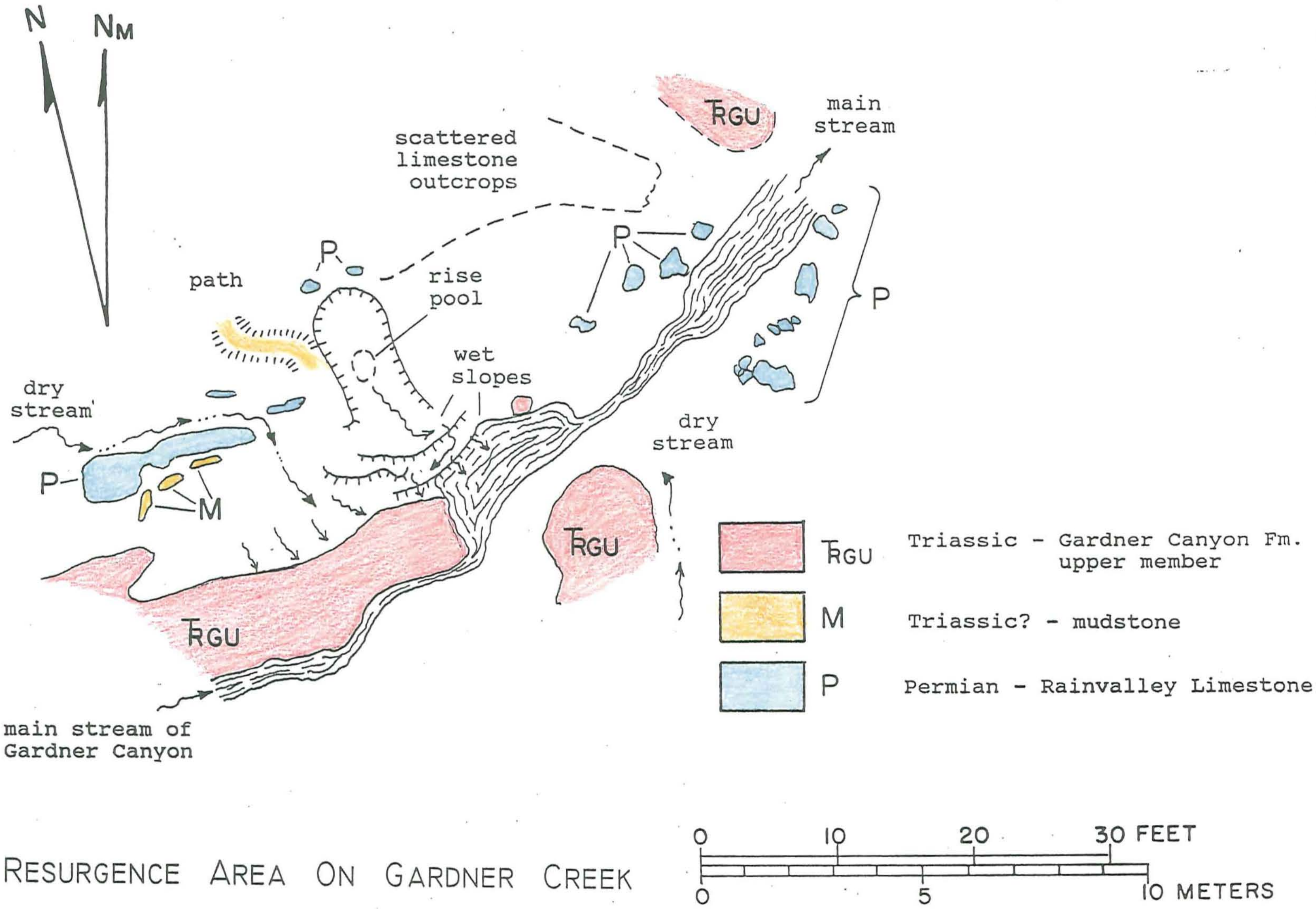
A reconnaissance along Gardner Creek, where the third outcrop of Rainvalley limestone occurred, revealed a small resurgence where water was flowing from a small pool about two meters above the creek bed. The status of this resurgence was checked at intervals; The flow from the resurgence ceased on several occasions after long intervals of meager rainfall. It is considered likely that this resurgence is fed from Onyx Cave; there is no other likely source. A map of the resurgence area is shown in Figure 14.

No other possible resurgences occur to the southeast, as the extension of the Rainvalley bed is lost under Cenozoic gravel. The approximate flow was measured with a 4-liter pail and a watch at a time when the flow was relatively strong, and it was found that the discharge was about 2000 gallons per day (equivalent to 7.57 cubic meters per day).

When the flow ceases the rise pool becomes completely dry. Conversely, when the resurgence is running, the water cascades down a number of step-like terraces to the creek, and fractures in the red (upper member) siltstone close to the creek bed exude small seeps. The presence of the resurgence on Gardner creek is perhaps facilitated by the presence of two closely spaced faults crossing the creek at this locality, as shown near the east edge of Plate 3.



STREAM HYDROLOGY ALONG CAVE CREEK NEAR ONYX CAVE FIGURE 13



RESURGENCE AREA ON GARDNER CREEK

FIGURE 14

STRATIGRAPHIC COLUMN FOR SELECTED AREAS
NORTHEAST SANTA CRUZ COUNTY, ARIZONA

ERA	SYSTEM	FORMATION	MEMBER	LITHOLOGY, LOCATION, CHARACTERISTICS, COMMENTS
CENOZOIC	QUATERNARY	N/A	N/A	POST PLEISTOCENE TO RECENT ALLUVIUM
		N/A	N/A	PLEISTOCENE TERRACES
	TERTIARY	N/A	N/A	PRE-PLEISTOCENE ALLUVIAL FANS
		N/A	N/A	RHYOLITE DIKE
MESOZOIC	CRETACEOUS	FT. CRITTENDEN	B.C.	PERIPHERAL, SOUTHWEST SIDE OF ONYX HILL
	TRIASSIC	GARDNER CANYON	UPPER	MAINLY RED SILTSTONE, LESSER SILTSTONE OF OTHER COLORS, MINOR RED SANDSTONE CONGLOMERATE, THIN LIMESTONE MARKER BEDS VOLCANIC COMPONENTS NOT PRESENT
			LOWER	TAN SILTSTONE, MINOR RED SANDSTONE THIN LIMESTONE MARKER BEDS, MINOR SEDIMENTARY BRECCIA, LOWER SAWMILL MAP
PALEOZOIC	PERMIAN	RAINVALLEY	N/A	PRIMARILY LS, SS & SILTSTONE NOT OBSERVED ON ONYX HILL, DOLOMITE NOT IDENTIFIED MUDSTONE PRESENT AT RESURGENCE
		CONCHA	N/A	CHERTY, FOSSILIFEROUS LIMESTONE PRESENT ON APACHE RIDGE AND BELLS RIDGE
		SCHERRER	4 MEMBERS	3 MEMBERS PRESENT ON ONYX HILL LOWER MEMBER PRESENT ON HILTON RIDGE? BASAL SILTSTONE MEMBER NOT PRESENT
		EPITAPH	UPPER	LS, SOME DOLOMITE, IN MOST MAP AREAS
			LOWER	LOWER MEMBER NOT PRESENT IN MAP AREAS
		COLINA	N/A	LS, MINOR CHERT, PRESENT IN MOST AREAS
	PENNSYLVANIAN PERMIAN	EARP?	N/A	PRESENT IN LOWER SAWMILL CANYON?
	MISSISSIPPIAN DEVONIAN SILURIAN ORDOVICIAN CAMBRIAN			NOT PRESENT IN MAPPED AREAS
PRE C.	CONTINENTAL GRANODIORITE PRESENT NORTH OF SAWMILL CANYON			

B.C, = BROWN CONGLOMERATE OF CRETACEOUS SYSTEM, SOUTH OF CAVE CREEK.

FIGURE 15

References

Bryant, Donald L. 1968 Diagnostic Characteristics of the Paleozoic Formations of Southeastern Arizona: part of Southern Arizona Guidebook III, pp 33-47

Drewes, Harald 1972 Structural Geology of the Santa Rita Mountains, Southeast of Tucson, Arizona: USGS Professional Paper 748; 35 pp, 4 maps

______________ 1980 Tectonic Map of Southeastern Arizona: USGS Misc. Investigation Series, Map I-1109

Moore, Raymond C., Lalicker, Cecil G., and Fischer, Alfred C. 1952 Invertabrate Fossils: 766 pp

Appendix I - Methodology

The methods described here were developed over several decades of surveying, initially in cave surveying and later in the surveying of surface geology. The emphasis is on simple instruments for single person use, employing hand-held devices.

The primary instruments are a sighting compass, Suunto KB-360, which utilizes a 0-360 degree, liquid damped drum dial. The compass contains a magnifying lens to observe the drum at the same time the user observes the target station over the top of the compass case. The instrument is fitted with a lanyard which can be worn around the neck and stored in a shirt pocket. The clinometer is similar to the compass; it employs a liquid damped drum which can be read through a magnifying lens at the same time as the target station is seen. The clinometer is also fitted with a lanyard. The instrument is graduated both in percent grade and degrees, but only the degree readings are used.

Length measurements are made with a fiberglass tape graduated in feet, tenths and hundredths of a foot; only the feet and tenths are read and recorded. The tape is stored in a light-weight plastic reel with a wind-up handle. A steel folding hook installed at the leading end of the tape was removed and replaced with a V-shaped stainless steel wire. The apex of the V was made to correspond with the zero end of the tape. A six-foot length of thin nylon cord was attached to the V for attachment of the tape to a sighting station.

In use, the leading end of the tape is attached to a starting station with the nylon cord, and the tape is unreeled until a target station is reached, at which the tape is draped over the target so that the tape is taut. Readings of tape length, compass reading, and clinometer reading are then recorded on the survey sheet, along with the identifying station numbers.

Recording of the survey data is made on a sheet of 8.5 by 11 inch quadrille paper clipped to a 9 by 12 inch clipboard. Also attached to the clipboard are a 6-inch rule, graduated in inches and tenths of inches. a 360 degree protractor, and an automatic pencil with an attached eraser. All three items are attached with short lengths of thin nylon cord so that they cannot be lost. The plastic protractor is a Sterling No. 535, 3.5 inches in diameter, fitted with a thin 3.5 inch acrylic backup plate for protection.

Prior to use, the sheet of quadrille paper is clipped to the clipboard; the geographic location, survey location, date, and page number are recorded in the upper left corner of the sheet. On the upper right is the tabulation of the data: origin station, next station, station line length, compass reading, clinometer reading, and two initially blank columns. The first column is intended to be used for the foreshortened station line length; the second is used to record the plotted length as determined by the scale factor. The two columns are used by the author when manually plotting the data. The space between the title data and the tabulated readings can be use for a brief description of the station.

The recorded data is plotted on the lower half of the paper, bearing in mind that the data tabulation will become longer as more data is recorded. Strike and dip readings, if made, can be recorded in unused places on the recording sheet. Experience has shown that all data for a single mapped area should be on a single survey data sheet, at least initially.

When a survey sheet has been sufficiently filled, it can be removed from the clipboard and placed in a fairly stiff plastic envelope, which is also where unused quadrille sheets are stored. In later surveys of the same area, segments of the previous survey may be included in a subsequent survey sheet, thus providing a starting area where the next survey can start.

Survey stations are selected from various natural objects which occur on the area to be mapped. Trees are often ideal, as they can provide stations near eye level and above obstructions on the ground. The best trees are ones with sizable, non-flexing branches. Thin limbed bushes and trees are avoided, as well as trees with many bushy branches, such as some cedars. A branch 3/4 to one inch in diameter, perhaps connected to a larger nearby branch, is often ideal. Other station sites may include isolated rocks with a pointed upper end, to which the tape can be attached.

Whatever natural item was used, it had to provide a relatively clearly visible position, sufficiently high above the ground so that the tape was not caught on low grass, bushes, or rocks. Non-natural features were sometimes used, provided they were non-magnetic. Steel fence posts have been used as stations, but it is necessary to take compass readings some distance from the fence.

In one instance, on the crest of a hill, no natural station could be found, so it was necessary to erect an artificial station using a garden stake. The stake was tethered with three cords tied to the stake and to small stakes set in the ground at 120 degree positions. After use, the stakes were removed but a marker was left at the base of the central stake for possible future recovery.

The angular accuracy of the Suunto hand-held compass is lower for higher inclined sightings, so station networks were employed in some cases. In this method parallel survey lines, perhaps 50 feet apart, were interconnected with intermediate survey lines, forming a number of interconnected triangles. This method was used with some success on the steep southwest side of Onyx Hill.

Geologic Aspects Of The Survey

Despite some small errors in the compass and tape surveys described in this report, the result was considerably more accurate than the use of aerial photographs. In some cases, the survey areas occurred beneath forest cover, thus precluding the use of aerial photos. Also, the scale factor, 50 feet per inch, provided a much more accurate illustration of surface geology.

In some cases, the contact, such as that between limestone and siltstone, was so obvious it was easily plotted. For such cases, the survey line was placed close to the contact (generally less than 10 feet) and its position was drawn on the survey. The same method was used for exposed fault traces. For less clearly defined contact and faults, the estimated position of separated outcrops was plotted by measuring along the tape for an outcrop and estimating the distance of the outcrop from the tape. For larger outcrop areas, an effort was made to draw the outcrop to scale.

Strike and dip readings were made with a magnetically damped Brunton compass wherever the bedding plane or fault surface was visible. Inferred faults were drawn with dashed lines when not readily apparent. In some cases, the apparent displacement of the thin limestone marker beds in the thicker siltstone beds (as noted by Drewes) was utilized to define a fault trace.

Small samples of various outcrops were obtained and examined, in some cases with a 10 power Hastings triplet magnifier. Relative hardness of samples was tested using a steel scribe. The relative reaction of samples was tested with dilute hydrochloric acid. A small magnet was used to test for possible magnetic activity, but none was found. The color of selected samples and differences of various samples was examined using the Munsell Soil Color Chart (handbook), as described in Appendix 2. A monocular microscope was available but not used.

Two minerals were found in readily identifiable form on the surface. A number of large loose crystals of quartz were identified by their crystal habit. Some large crystalline calcite was readily identified by its internal cleavage. A number of small pieces of hematite were tentatively identified by their appearance; some of these pieces were found in the vicinity of a test hole near the Arizona Trail.

A number of fossils were observed, most in a limestone matrix. The large gastropod, Omphalotrochus, was noted in a number of places and was often displayed on a plane perpendicular to its central axis. The large brachiopod, Dictyoclostus, was observed silicified with chert in limestone, and were observed inside Onyx Cave. Bryozons were observed near the crest of Apache Ridge in Permian limestone. Identification, when possible, was made with the aid of Invertebrate Fossils (Moore, Lalicker, and Fischer, 1952).

Appendix 2

Survey Markers On and Near Apache Ridge

Three survey markers were found during surveys of Apache Ridge. One marker was found within the survey area and two were found on the periphery of the area. Others may be present but were not found. The three markers are listed in the sequence of their discovery.

First survey marker found: Reference - Survey 8, page 1
Location: About 10 feet north of FR-92, about 1 foot west of the barbed wire fence, east of Arizona Trail parking area
Markings: PE5135 No. 8A SW 1/16 S6
Setting: Short metal pipe,

Second survey marker found: Reference - Survey 34, page 2
Location: South edge of FR-92, about 205 feet west of elbow on water pipe below steel water tank; a short distance from Apache Spring.
Markings: C S 1/16 S6 PE5145

Third Survey marker found: Reference - Survey 274, page 1
Location: About 90 feet east of straight section of Arizona Trail, and about 120 feet south of ravine near north side of the limestone outcrop.
Setting: short metal pipe in rock cairn.

Appendix 3

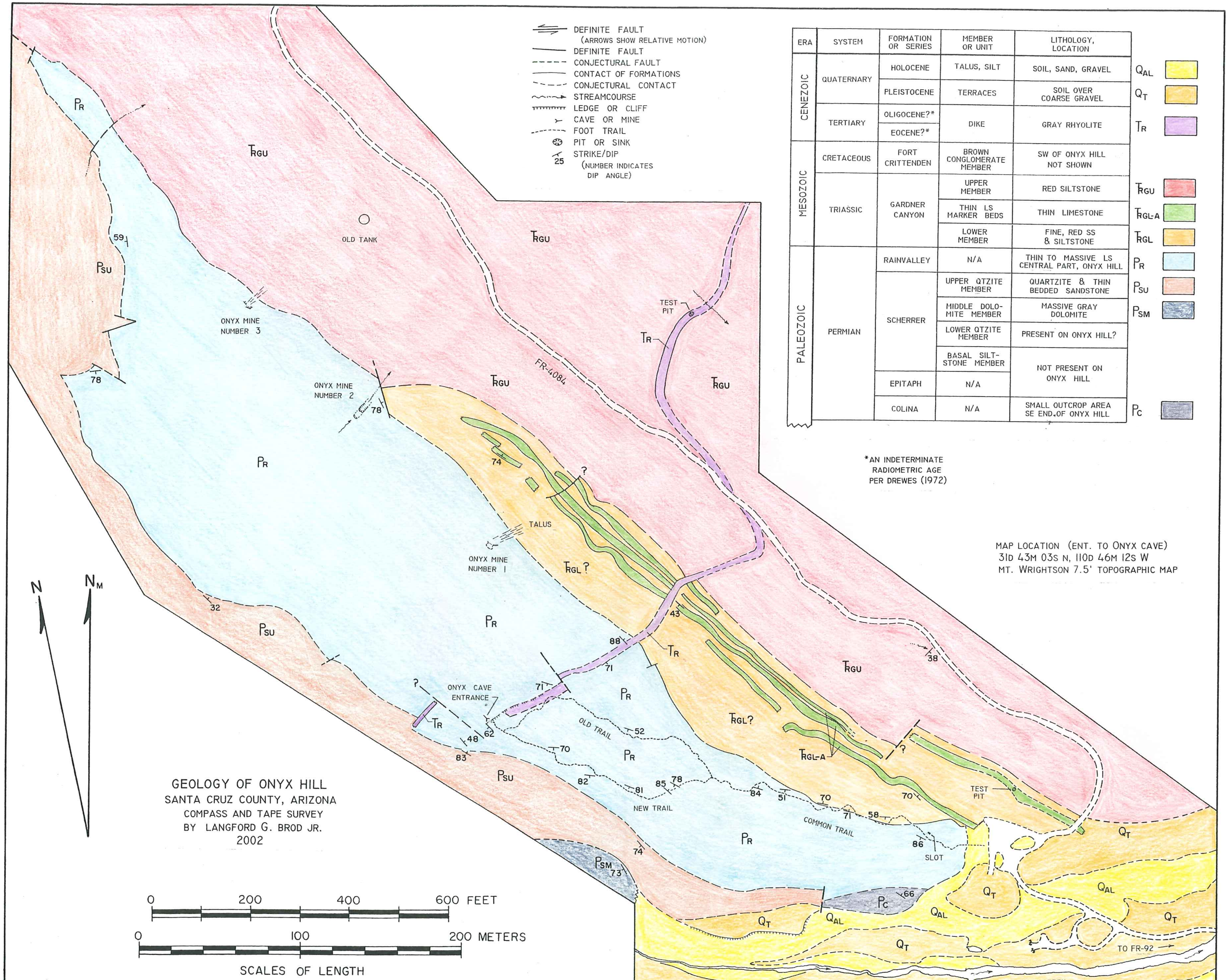
White Limestone Bed, Eastern Apache Ridge

An outcrop of white limestone was found near the eastern end of Apache Ridge, not far below the crest. The bed occurred at the north edge of Colina outcrops, at the contact with siltstone of the Gardner Canyon Formation. This bed was in sharp contrast with the Adjacent Colina outcrops, which are generally black limestone which weather to a dark gray color.

On closer examination, the white rock is observed to contain small specks of a darker color. Under low magnification, the specks are shown to be semi-transparent, appearing to be small masses of calcite. Treatment with dilute hydrochloric acid causes obvious effervescence on both the darker inclusions and the white matrix which comprises the majority of the rock. It appears that the dark color of the inclusions is an optical property in which incident light entering the calcite specks is lost internally.

The specks of calcite range up to about 3 mm in size, though many are smaller. The position appears to be aligned along a rather irregular bedding, though this is a somewhat tentative conclusion.

The white rock does not resemble any other outcrops on Apache Ridge or the other geologic areas nearby. In addition, it does not resemble any of the beds in the underlying Earp Formation with which this author is familiar. On Plate 3 of USGS Professional Paper 748. Drewes shows an Earp outcrop area about 2.5 Kilometers west-northwest of the Apache Ridge area. Unfortunately, this author has not observed this Earp outcrop or others northwest of that site. Drewes' general description for the Earp Formation is "Reddish and yellowish-brown sandstone, siltstone, and marlstone", which does not match the observation on Apache Ridge.



ERA	SYSTEM	FORMATION OR SERIES	MEMBER OR UNIT	LITHOLOGY, LOCATION		
CENEZOIC	QUATERNARY	HOLOCENE	TALUS, SILT	SOIL, SAND, GRAVEL	Q_{AL}	
		PLEISTOCENE	TERRACES	SOIL OVER COARSE GRAVEL	Q_T	
	TERTIARY	OLIGOCENE?*	DIKE	GRAY RHYOLITE	T_R	
		EOCENE?*				
MESOZOIC	CRETACEOUS	FORT CRITTENDEN	BROWN CONGLOMERATE MEMBER	SW OF ONYX HILL NOT SHOWN		
	TRIASSIC	GARDNER CANYON	UPPER MEMBER	RED SILTSTONE	TR_{GU}	
			THIN LS MARKER BEDS	THIN LIMESTONE	$TR_{GL\text{-}A}$	
			LOWER MEMBER	FINE, RED SS & SILTSTONE	TR_{GL}	
PALEOZOIC	PERMIAN	RAINVALLEY	N/A	THIN TO MASSIVE LS CENTRAL PART, ONYX HILL	P_R	
		SCHERRER	UPPER QTZITE MEMBER	QUARTZITE & THIN BEDDED SANDSTONE	P_{SU}	
			MIDDLE DOLOMITE MEMBER	MASSIVE GRAY DOLOMITE	P_{SM}	
			LOWER QTZITE MEMBER	PRESENT ON ONYX HILL?		
			BASAL SILTSTONE MEMBER	NOT PRESENT ON ONYX HILL		
		EPITAPH	N/A			
		COLINA	N/A	SMALL OUTCROP AREA SE END OF ONYX HILL	P_C	

GEOLOGY OF ONYX HILL
SANTA CRUZ COUNTY, ARIZONA
COMPASS AND TAPE SURVEY
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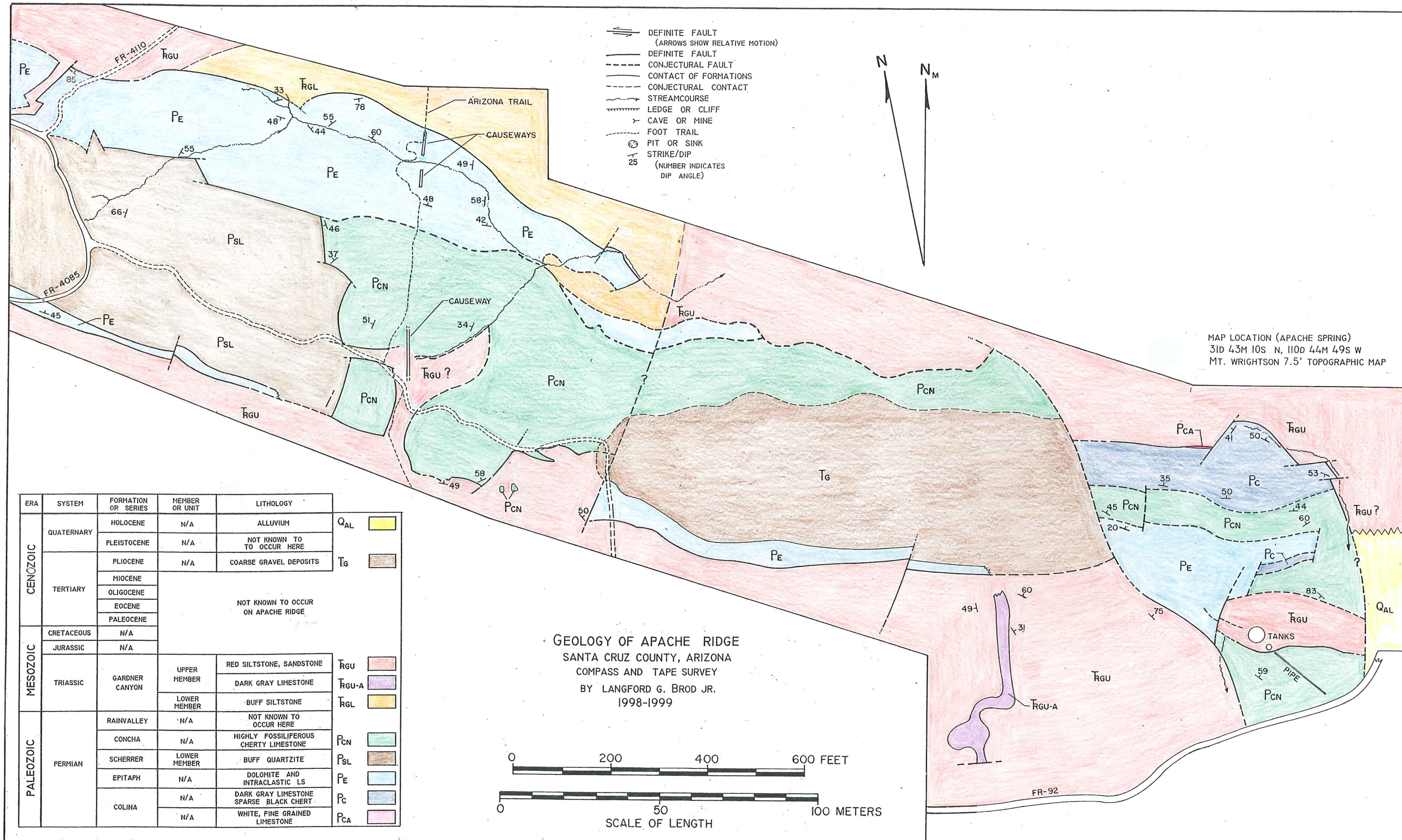
2002



GEOLOGY OF APACHE RIDGE

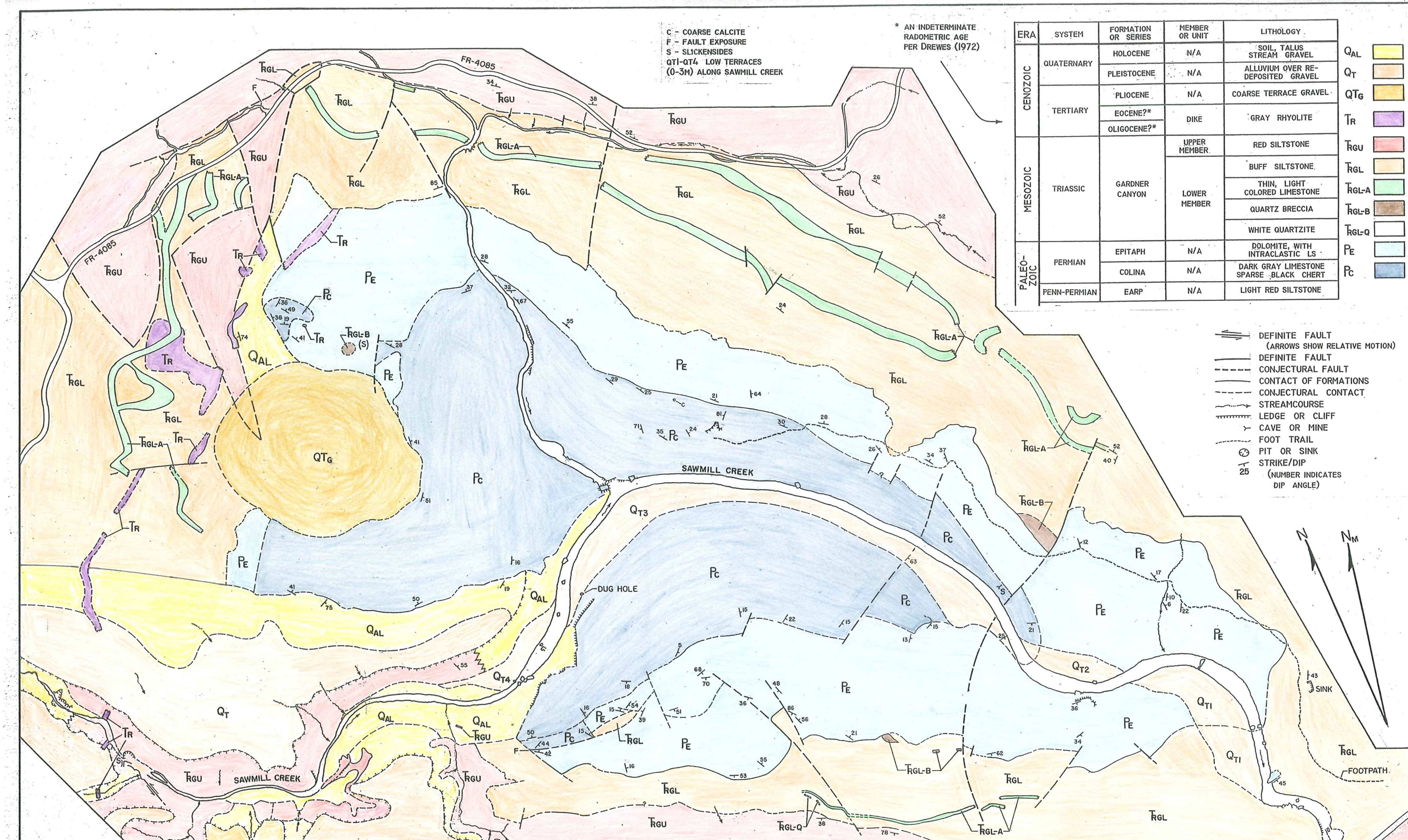
SANTA CRUZ COUNTY, ARIZONA

COMPASS AND TAPE SURVEY

BY LANGFORD G. BROD JR.

1998-1999

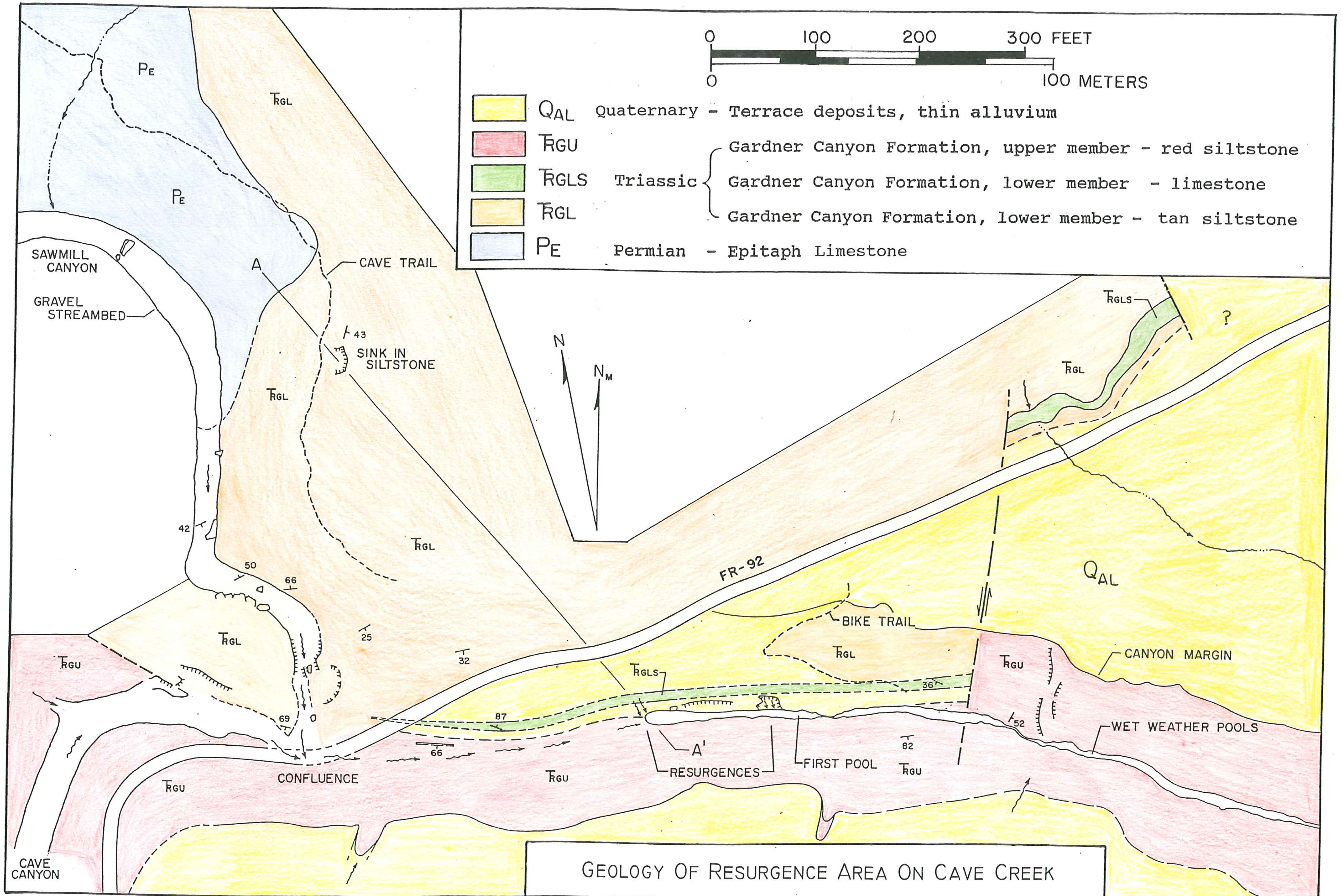
ERA	SYSTEM	FORMATION OR SERIES	MEMBER OR UNIT	LITHOLOGY	
CENOZOIC	QUATERNARY	HOLOCENE	N/A	ALLUVIUM	QAL
		PLEISTOCENE	N/A	NOT KNOWN TO TO OCCUR HERE	
	TERTIARY	PLIOCENE	N/A	COARSE GRAVEL DEPOSITS	TG
		MIOCENE	NOT KNOWN TO OCCUR ON APACHE RIDGE		
		OLIGOCENE			
		EOCENE			
		PALEOCENE			
MESOZOIC	CRETACEOUS	N/A			
	JURASSIC	N/A			
	TRIASSIC	GARDNER CANYON	UPPER MEMBER	RED SILTSTONE, SANDSTONE	TRGU
				DARK GRAY LIMESTONE	TRGU-A
			LOWER MEMBER	BUFF SILTSTONE	TRGL
PALEOZOIC	PERMIAN	RAINVALLEY	N/A	NOT KNOWN TO OCCUR HERE	
		CONCHA	N/A	HIGHLY FOSSILIFEROUS CHERTY LIMESTONE	PCN
		SCHERRER	LOWER MEMBER	BUFF QUARTZITE	PSL
		EPITAPH	N/A	DOLOMITE AND INTRACLASTIC LS	PE
		COLINA	N/A	DARK GRAY LIMESTONE SPARSE BLACK CHERT	PC
			N/A	WHITE, FINE GRAINED LIMESTONE	PCA



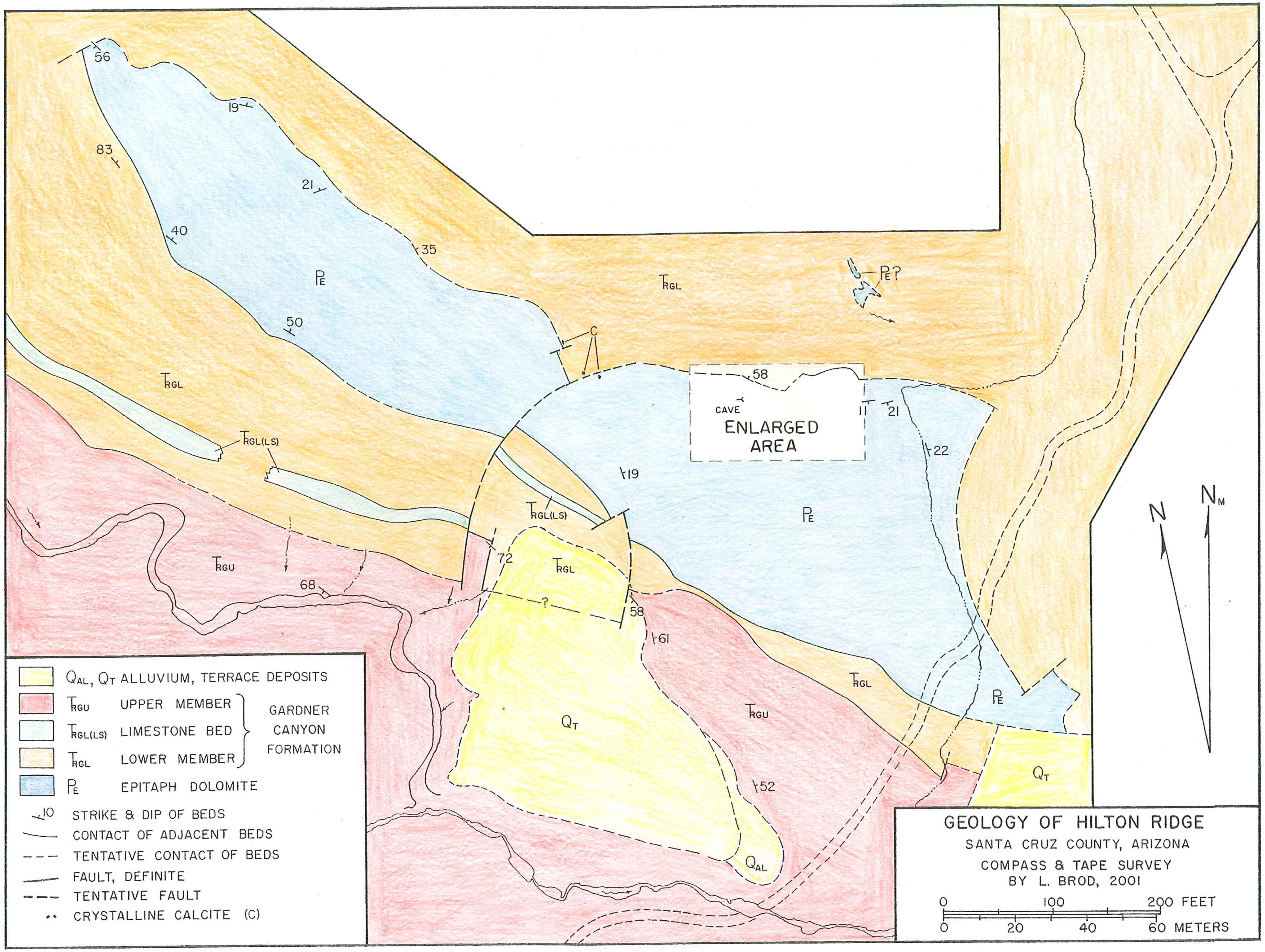
GEOLOGY OF LOWER SAWMILL CANYON

SANTA CRUZ COUNTY, ARIZONA
COMPASS AND TAPE SURVEY
BY LANGFORD G. BROD JR.
1999-2003

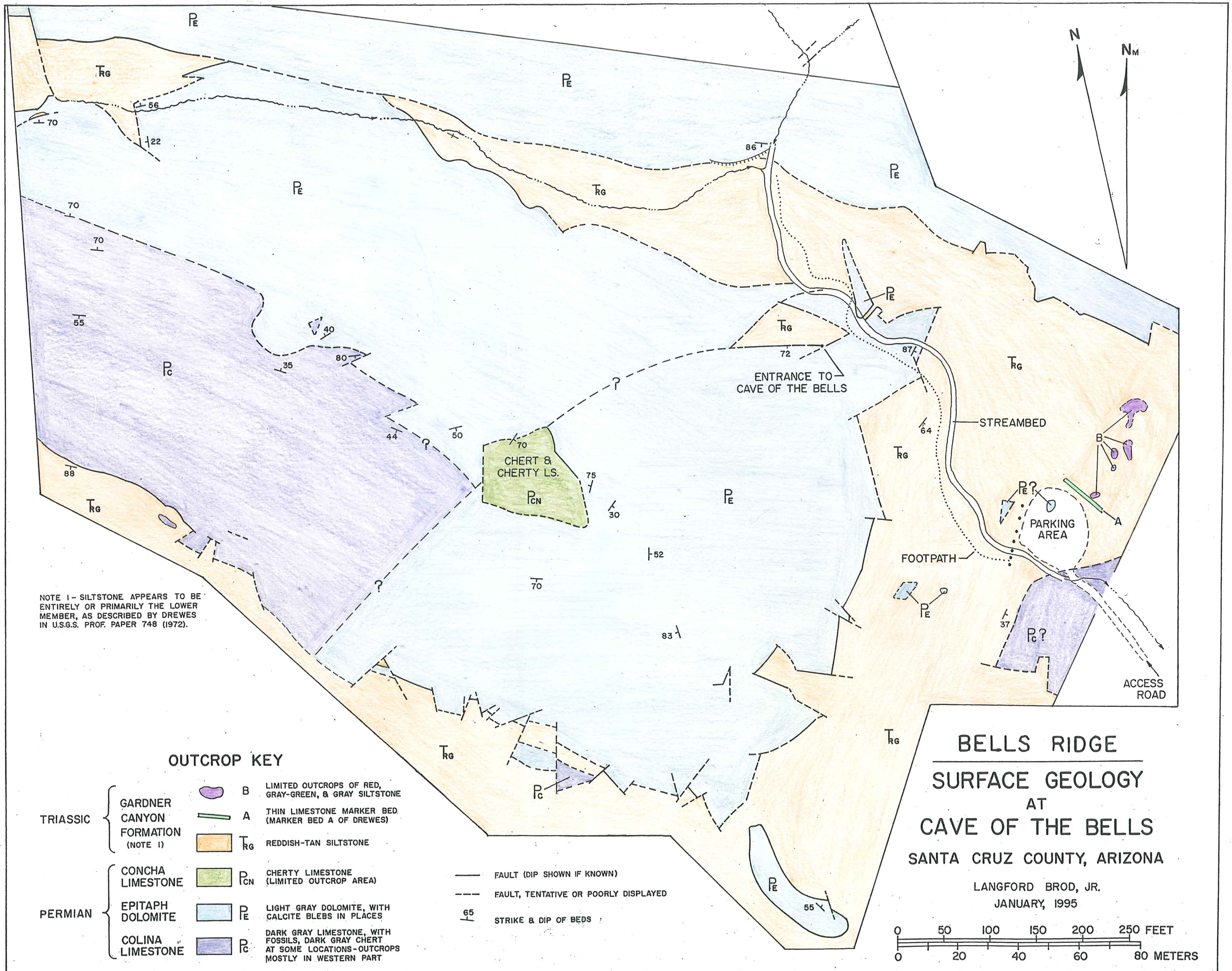
MAP LOCATION (CONFLUENCE)
31D 43M 08S N, 110D 45M 28S W
MT. WRIGHTSON 7.5' TOPOGRAPHIC MAP



GEOLOGY OF RESURGENCE AREA ON CAVE CREEK



56
19
83
21
40
35
P_E
T_{RGL}
P_E?
50
C
58
CAVE
ENLARGED AREA
21
22
T_{RGL}
$T_{RGL(LS)}$
19
P_E
$T_{RGL(LS)}$
N
N_M
T_{RGU}
72
T_{RGL}
68
?
58
61
T_{RGL}
P_E
Q_T
T_{RGU}
52
Q_T
Q_{AL}
Q_{AL}, Q_T ALLUVIUM, TERRACE DEPOSITS
T_{RGU} UPPER MEMBER
$T_{RGL(LS)}$ LIMESTONE BED
T_{RGL} LOWER MEMBER
GARDNER CANYON FORMATION
P_E EPITAPH DOLOMITE
10 STRIKE & DIP OF BEDS
CONTACT OF ADJACENT BEDS
TENTATIVE CONTACT OF BEDS
FAULT, DEFINITE
TENTATIVE FAULT
CRYSTALLINE CALCITE (C)
GEOLOGY OF HILTON RIDGE
SANTA CRUZ COUNTY, ARIZONA
COMPASS & TAPE SURVEY
BY L. BROD, 2001
0 100 200 FEET
0 20 40 60 METERS


BELLS RIDGE
SURFACE GEOLOGY
AT
CAVE OF THE BELLS
SANTA CRUZ COUNTY, ARIZONA
LANGFORD BROD, JR.
JANUARY, 1995
N
NM
ENTRANCE TO CAVE OF THE BELLS
STREAMBED
PARKING AREA
FOOTPATH
ACCESS ROAD
CHERT & CHERTY LS.
NOTE 1 - SILTSTONE APPEARS TO BE ENTIRELY OR PRIMARILY THE LOWER MEMBER, AS DESCRIBED BY DREWES IN U.S.G.S. PROF. PAPER 748 (1972).
OUTCROP KEY
TRIASSIC
GARDNER CANYON FORMATION (NOTE 1)
B LIMITED OUTCROPS OF RED, GRAY-GREEN, & GRAY SILTSTONE
A THIN LIMESTONE MARKER BED (MARKER BED A OF DREWES)
TRG REDDISH-TAN SILTSTONE
PERMIAN
CONCHA LIMESTONE
PCN CHERTY LIMESTONE (LIMITED OUTCROP AREA)
EPITAPH DOLOMITE
PE LIGHT GRAY DOLOMITE, WITH CALCITE BLEBS IN PLACES
COLINA LIMESTONE
PC DARK GRAY LIMESTONE, WITH FOSSILS, DARK GRAY CHERT AT SOME LOCATIONS-OUTCROPS MOSTLY IN WESTERN PART
FAULT (DIP SHOWN IF KNOWN)
FAULT, TENTATIVE OR POORLY DISPLAYED
65 STRIKE & DIP OF BEDS
0 50 100 150 200 250 FEET
0 20 40 60 80 METERS